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INVESTIGATION OF PROPELLANT SYSTEMS FOR HIGH-PERFORMANCE GUNS

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INVESTIGATION OF PROPELLANT SYSTEMS FOR HIGH-PERFORMANCE GUNS

—Final Report—

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I. SUMMARY

Several theoretical studies were made in this country after World War II to evaluate the impulse propulsion gun suggested by Langweiler as a means of increasing projectile velocity. These studies led to the initiation of experimental programs at the Ballistic Research Laboratory, Aberdeen, Maryland, and at the Atlantic Research Corporation. The approach at the Ballistic Research Laboratory has been the development of new, unconventional propellant systems with extremely high effective burning rates to be used as end-burning charges to achieve performance near that of an impulse gun. The approach at Atlantic Research, on the other hand, has been the utilization of properly shaped charges of conventional propellant traveling with the projectile — an approach suggested as a possible means of achieving substantially the performance of the impulse gun in the theoretical investigations made at Atlantic Research.

The initial goal of the program undertaken at Atlantic Research was the experimental verification of the higher theoretical performance predicted for "modified impulse guns."

It is the purpose of this report to summarize the results of this program.

A description of the gun range which was constructed to conduct experimental firings is given. The range consists of a gun housing, a control and instrument building and a gun butt.

Two 1.1-inch machine gun barrels were modified at the Naval Gun Factory for use in the experimental firings. Schematic drawings and descriptions of these two barrels, designated Gun A and Gun B, are given together with descriptions of the cartridge cases and igniters developed for use in each gun.

The modified 1.1-inch guns were not entirely satisfactory for use in this study, the major difficulty being the design and fabrication of progressive propellant charges with small web. If additional studies are conducted, it is suggested that a 3"/70-caliber gun be employed.

A gun firing system and associated instrumentation was developed to measure gun pressure in the chamber and at five positions along the bore. Both expanding-cylinder and piston-type gages using resistance strain gages as the sensitive element were fabricated for pressure measurement. A special pressure gage-igniter combination which fitted into the cartridge case was developed to measure chamber pressure.

Projectile velocity was measured using either photoelectric screens or conducting glass slides to trigger a 1.6mc counter chronograph. Muzzle velocity obtained by measuring time between two pips on a photograph of an oscilloscope trace was found to be inaccurate due to lack of precision in measuring the time interval.

A closed bomb was designed and constructed. The bomb was tested at pressures up to 40,000 psi.

The results of firings with conventionally loaded charges of SPDN 3256 have been analyzed. These propellant grains were found not to be completely burned under the experimental firing conditions. An empirical form function was derived which gave good agreement between calculated and observed gun performance. Superior ignition was obtained with the ARC igniter as compared with Mark 42 igniters in firings with SPDN 3256.

A progressive charge was fabricated by inhibiting 0.078-inch-thick JPN propellant with a 0.003-inch film of ethyl cellulose and by making cuts one-sixteenth inch apart through the inhibitor on both sides of the sheet. It was found that propellant prepared in this manner was extremely difficult to ignite in gun firings.

Stacked disks of JPH propellant 0.020 inch thick with an eccentric one-fourth-inch-diameter hole in each disk were cemented to the base of several projectiles. These charges were fired in combination with conventionally loaded SPDN 3256. In addition, comparison firings were made with the entire charge conventionally loaded. Both average pressure and muzzle velocity for the conventional rounds were higher than observed in firings with the JPH disks attached to the projectile.

Firings were made with either IX107 or M-7 propellant grains attached to the projectile in combination with conventionally loaded SPDN 3256. Somewhat higher muzzle velocity and lower pressures

were obtained in firings with these grains attached as compared with firings in which the total charge was conventionally loaded. When either IX107 or M-7 grains were attached to the projectile the end caps which initially restrained the grains in cavities in the projectile base were deformed enough to allow the grains to escape.

Porous grains were cast in projectile cavities by cementing together pre-plasticized nitrocellulose ball powder. Little burning occurred in the first firing with this charge. A second firing was made with a porous attached charge and a 60-gram charge of SPDN 3256 conventionally loaded. Extremely high pressures in this firing irreparably damaged the barrel and breech of Gun A.

A series of firings were made with the propellant charge loaded in a perforated steel basket attached to the base of the projectile. The average muzzle velocity for these firings was about 200 ft/sec higher than the average muzzle velocity recorded in firings with the same charge and the projectile weight in which the propellant was conventionally loaded. The maximum pressures recorded at the various gage positions were higher when the charge was loaded in the basket, and a reasonably constant pressure was obtained during the first 15 inches of projectile travel.

In each firing with a basket-type projectile, structural failure of the basket occurred, the tail-piece usually separating from the body of the basket. It is suggested that further investigation of basket-type projectiles be undertaken to determine the mechanism of their structural failure during firing.

A projectile was designed into which was cast a small web, ninety-one-perforated grain. These grains were made using plastisol-grade nitrocellulose. Only one round was fired, however, before the program was terminated. It is suggested that the use of grains of this type as attached charges be further investigated.

An interior ballistic system was developed to calculate, for a given set of loading conditions and with assumed values of maximum pressure and muzzle velocity, explicit values of shot-start pressure and retarding force on the projectile. Calculated maximum pressure and muzzle velocity using calculated values of shot-start pressure and retarding force on the projectile (determined from observed values of maximum pressure and muzzle velocity obtained under other firing conditions) were in good agreement with those observed.

Theoretical investigation of the effect of density gradient in the propellant gases upon the ratio of breech pressure to pressure on the base of the projectile led to the conclusion that variation of gas density down the bore has little effect on the magnitude of this ratio.

An interior ballistic system was developed to calculate the theoretical performance for firings in which a conventional charge is attached to the projectile, or when part of the propellant is conventionally loaded and part attached to the projectile. The equations forming the basis for this ballistic system are given.

Loading conditions and measured ballistic data for all firings in Gun A and Gun B are included.

II. INTRODUCTION

It has been recognized for many years that the effectiveness of projectiles fired at a target increases rapidly as the projectile velocity increases, and considerable work has been done toward increasing the muzzle velocity of guns. A novel approach to the achievement of high projectile velocities, the impulse propulsion gun,[13] was suggested in 1939 by Langweiler in Germany. The impulse gun differs from the conventional gun in that the propellant is attached to the base of the projectile and burns only on its rear surface. Langweiler imposed the further restriction that the propellant burning rate changes in such a way that the gases leaving the combustion zone are at rest relative to the gun tube and are at constant pressure. As compared with a conventional gun the impulse gun is superior as an accelerating device both from the viewpoint of propellant efficiency and distance efficiency, its advantages becoming more marked at higher muzzle velocities.[17]

After World War II, several studies were made in this country of the Langweiler impulse gun.[14,16,18] These studies led to the initiation of experimental programs at the Ballistic Research Laboratory, Aberdeen, Maryland, and at the Atlantic Research Corporation. The approach at the Ballistic Research Laboratory has been the development of new, unconventional propellant systems with extremely high effective burning rates which would be used as end-burning charges to achieve performance near that of an impulse gun. On the other hand, the approach at Atlantic Research has been the utilization of properly shaped charges of conventional propellant traveling with the projectile — an approach suggested as a possible means of attaining substantially the performance of the impulse gun in the theoretical investigations made at Atlantic Research.[16]

The initial goal of the program undertaken at Atlantic Research was the experimental verification of the higher theoretical performance predicted for "modified impulse guns."[16] This program was actively initiated in June, 1952 and continued until December, 1954, at which time the study was terminated. It is the purpose of this report to summarize the results of this program.

III. THE EXPERIMENTAL FACILITY

A. THE GUN RANGE

The gun range constructed for use in the experimental program consisted of three buildings; a gun housing, a control and instrument building, and a gun butt.

The gun housing was constructed on a heavy concrete base and enclosed the gun with 5/16-inch steel. The space around the gun inside the housing was just large enough to allow normal operations on the gun and breech.

The control and instrument building is a cinder-block structure with approximately 200 square feet of floor space divided into two rooms. This building is separated from the gun housing by a two-foot-thick sand barrier. Instruments and recording equipment used to obtain experimental firing data were installed in the larger of the two rooms in the control building. The second room, constructed with explosion-proof electrical fixtures and conducting floor, was used for propellant loading and handling and contained the equipment used to temperature condition rounds prior to firing.

The gun butt, approximately 50 feet from the muzzle of the gun, is a box fabricated from one-half-inch steel plate four feet in height and width and six feet deep with a removable front of masonite. This box is filled with sand and is enclosed in a reinforced concrete structure. It was found that approximately thirty rounds could be fired into the gun butt before the sand and front cover required replacement.

B. MODIFIED 1.1-INCH GUN

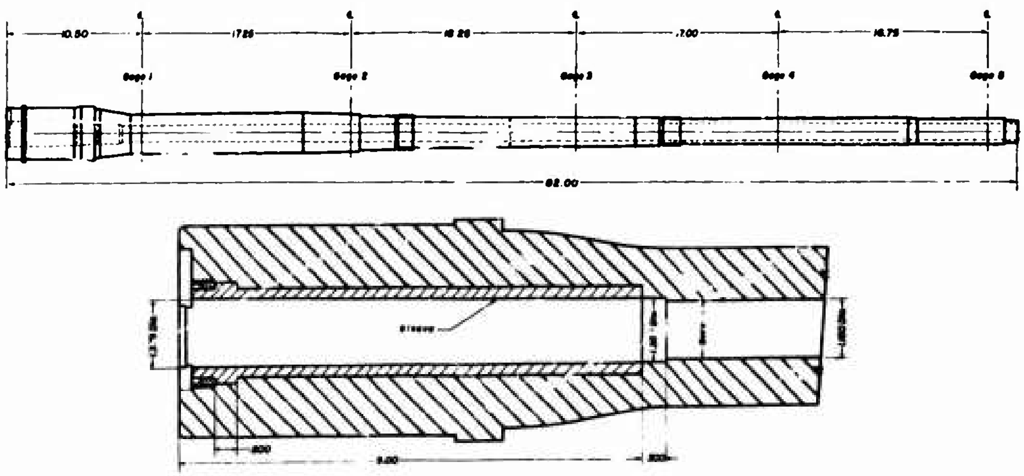
Experimental firings were conducted in one of two modified 1.1-inch machine guns. Gun A was used for all firings until it was damaged in Firing 136 during January 1954. Firings after this date were conducted in a second modified 1.1-inch gun designated Gun B.

1. Gun A

Gun A was modified at the Naval Gun Factory for use in experimental firings. The modifications to the gun consisted of (1) removal of the rifling and increasing the bore diameter to 1.150 inches, (2) insertion of a sleeve in the chamber to give a constant chamber cross-section through the base and cartridge case of 1.150 inches, and (3) drilling and threading five holes at intervals along the barrel to receive pressure gages. Use of the sleeve reduced the chamber volume by about 40 per cent as compared with the normal 1.1-inch gun. A schematic drawing of the modified 1.1-inch gun barrel is shown in Figure 1.

FIGURE 1

Modified 1.1-Inch Machine Gun Barrel for Gun A



a. Cartridge Cases and Igniters

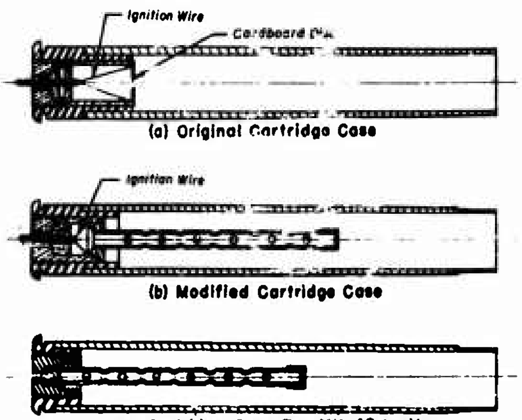
Three cartridge cases were developed for use with Gun A.[2] Schematic drawings of these cases are shown in Figure 2. The case and igniter shown in Figure 2(a) was fabricated from brass and used tungsten wire as the ignition element. The primer cavity was sufficiently large to hold up to 10 grams of black powder; however, it was found that adequate ignition was obtained with between two and three grams of FFFG black powder. Successful electrical insulation between the case and the lead to the ignition element was obtained by fabricating the insulators from cloth-filled phenolic. These insulators were cemented into place in the igniter.

A superior case was designed and used in Gun A after Firing 1?. This case was fabricated from steel with the wall thickness reduced to improve obturation. The size of the igniter was reduced and a flash tube was incorporated. A schematic drawing of this case and igniter is shown in Figure 2(b).

A third case and igniter, shown in Figure 2(c), was designed to use the Mark 42 ignition element. The volume of the igniter was thus further reduced. Firings with the Mark 42 element, however, indicated that the ignition delay was longer and ignition inferior to that obtained with the ARC igniter. As a result, few firings were made with this case and igniter.

FIGURE 2

Cartridge Cases and Igniters Developed for use with Gun A



(a) Original Cartridge Case

(b) Modified Cartridge Case

(c) Cartridge Case For MK-42 Igniter

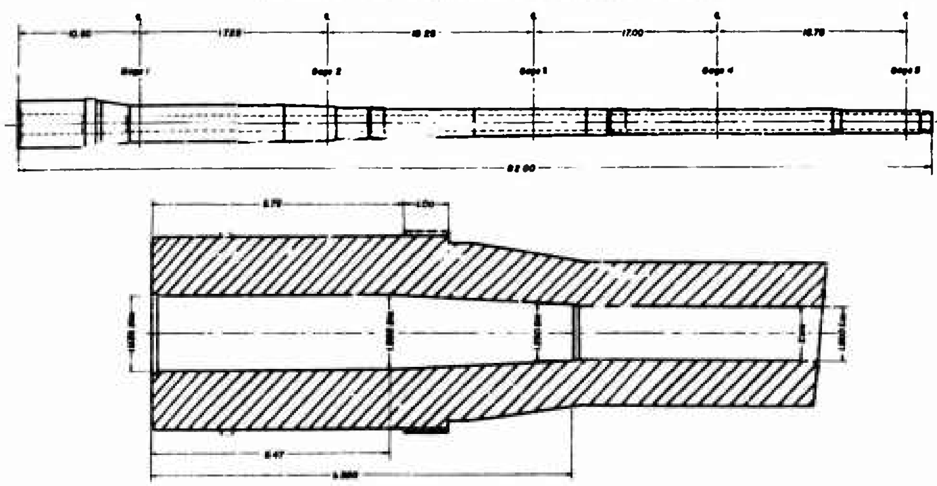
2. Gun B

After Gun A was damaged, a second 1.1-inch machine gun barrel was modified at the Naval Gun Factory. Because several changes were made in this new barrel as compared with the previous barrel,[6,7] the new gun was designated Gun B.

A schematic drawing of the barrel of Gun B is shown in Figure 3. To reduce propellant loading

FIGURE 3

Modified 1.1-Inch Machine Gun Barrel for Gun B



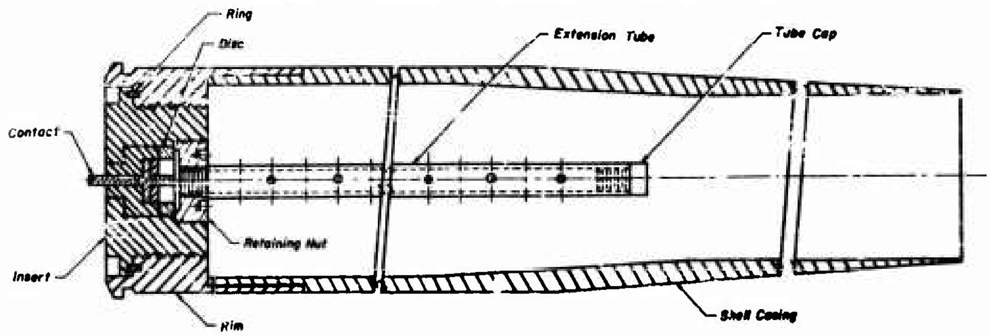
density, the chamber was enlarged as compared with Gun A by eliminating the sleeve previously used. A forcing cone was incorporated into the chamber design so that forcing bands could be used on the projectiles as a means of increasing shot-start pressure and reducing gas leakage. The bore diameter of the new barrel was increased to 1.200 inches and the barrel was chrome plated.

a. Cartridge Case and Primer

A new cartridge case and primer was developed[7] for use with Gun B, and the size of the primer was reduced to further increase the initial chamber volume. A schematic drawing of the case and primer is shown in Figure 4.

FIGURE 4

Cartridge Case and Primer Developed for Use with Gun B



C. INSTRUMENTATION DEVELOPED FOR MEASUREMENT OF BALLISTIC PARAMETERS

1. Measurement of Gun Pressure

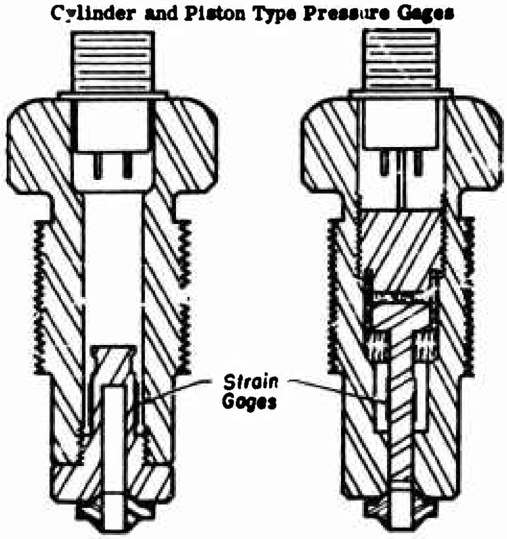
The barrels for both Gun A and Gun B were drilled so that pressure gages could be inserted at five positions along the barrel. (See Figures 1 and 3.) Pressure gages using resistance strain gages as the sensitive elements were fabricated to measure pressure.[8] The first gages developed were patterned after an expanding-cylinder type gage designed at the Naval Proving Ground, Dahlgren, Virginia. All gages used in the experimental program were calibrated in cooperation with the Naval Proving Ground. Figure 5(a) shows the construction details of the cylinder-type gage.*

A second type pressure gage was also developed. The strain element in this gage is mounted on a piston which is compressed by the gun pressure. Construction details of this gage are shown in Figure 5(b).

Measurement of chamber pressure was made possible by development of a pressure gage-igniter combination which fit into the cartridge case.[8] Figure 6(a) is a drawing of the igniter-pressure gage developed for use in Gun A. An improved

FIGURE 5

Cylinder and Piston Type Pressure Gages



(a) Cylinder Type (b) Piston Type

*The initial group of cylinder gages was found to have nonlinear response, particularly above 30,000 psi, due to the use of an incorrect type steel and improper hardening of the cylinder.

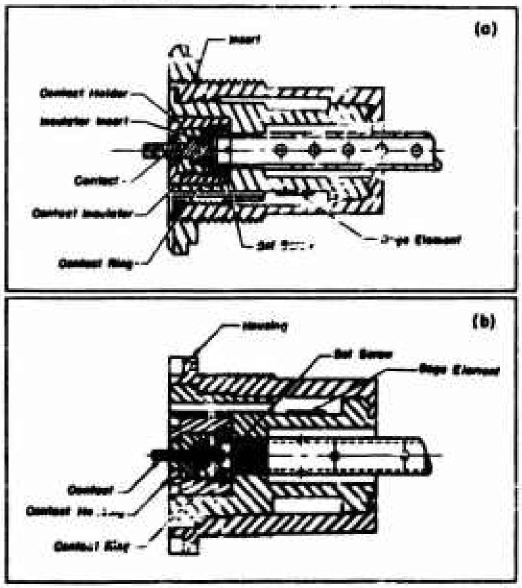
version of this gage was developed for use with Gun B. This gage was mechanically interchangeable with the standard igniter, the only effect resulting from its use being a slight reduction in chamber volume. Details of the igniter-pressure gage used in Gun B are shown in Figure 6(b).

Because these gages were used only to measure transients, a "dynamic" type circuit was designed using A. C. amplifiers and A. C. oscilloscopes. This system was much less expensive than a conventional bridge circuit with D. C. amplifiers. Figure 7 is the schematic of the pressure-gage circuit.

Recording of gun pressures was accomplished by feeding the output of the strain-gage circuit to preamplifiers and then to the vertical amplifier input of single-sweep oscilloscopes. The sweeps of the oscilloscopes were triggered by the burnout of the igniter wire in the primer. Z-axis modulation was used with the trace blanked at 0.5-millisecond intervals to provide timing markers.

FIGURE 6

Igniter-Pressure Gages Developed to Measure Chamber Pressure in Guns A and B

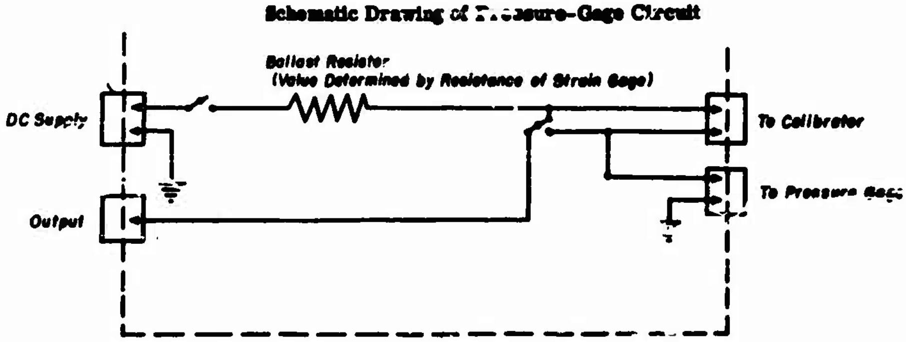


Photographic records of the traces on the oscilloscopes were made with special cameras constructed to use two-and-one-fourth-inches by three-and-one-fourth-inches cut film or with a rotating drum camera.* The special cameras were constructed with electric-shutter solenoids. However, because the beams were blanked until triggered it was found more convenient to leave the shutters open and pull the slides on the film holder to prepare the film for exposure.

Timing marks, which were superimposed on the pressure traces, were obtained by a time-marker generator. This device employed a tuning-fork oscillator, and it could be used to produce accurate

FIGURE 7

Schematic Drawing of Pressure-Gage Circuit



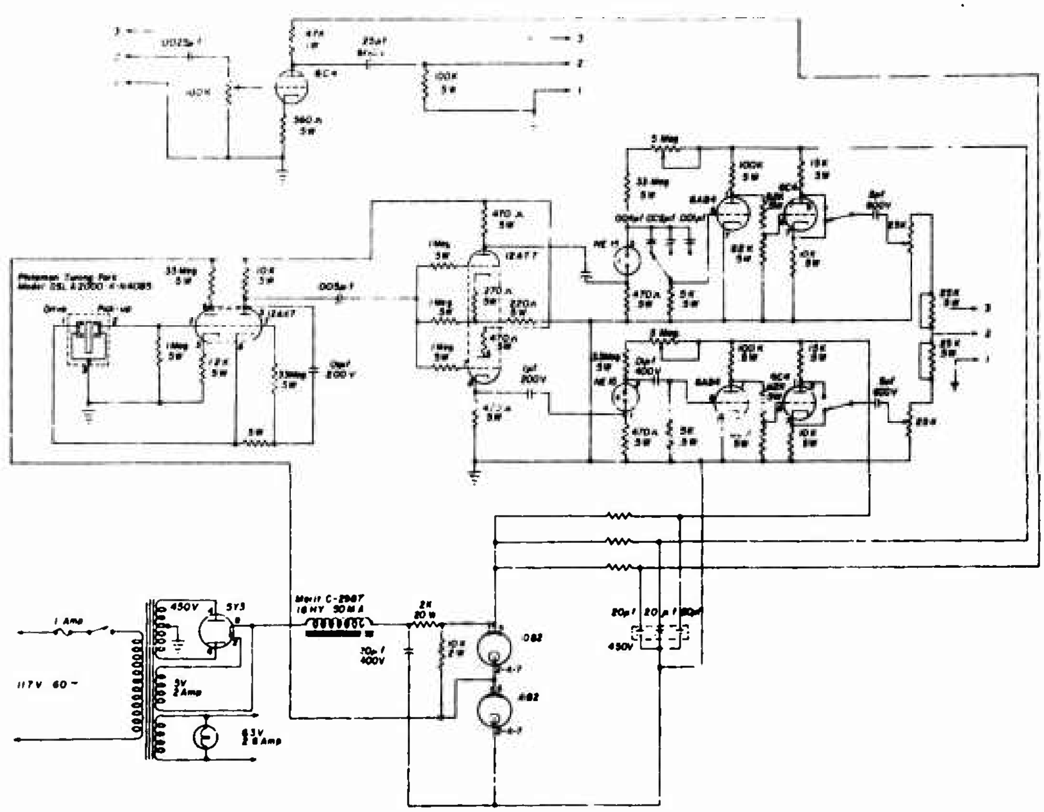
time markers of either polarity with periods of 0.5, 1.0, or 2.0 milliseconds. A four-millisecond pulse synchronized with other pulses was also available. The circuit of the time-marker generator is shown

*The drum camera was used with a dual-beam oscilloscope to record chamber pressure and pressure at the first gage position.

as Figure 8.

Three mechanisms were developed for calibrating the pressure traces, but none was completely successful. The first system used a "shorting" type wafer switch rotated rapidly by a spring mechanism.[1] The same calibration steps were applied simultaneously to all pressure gages. The primary sources of trouble with this system were deterioration of the silver-plated contacts on the switch, interference between the various gage circuits through the calibrator, the requirement of different height steps for various gages, and difficulties encountered in triggering the oscilloscopes for calibration.[8]

FIGURE 8
Circuit of Time-Marker Generator



A second calibrator was constructed using a motor-driven cam to operate six sets of three switches.[8] Thus, three switches in each gage circuit could be opened to calibrate the pressure trace with appropriate resistance steps. A relay was incorporated into the circuit to short out the calibration resistors after one rotation of the cam. The quality of the calibration traces produced by this system deteriorated rapidly with wear.

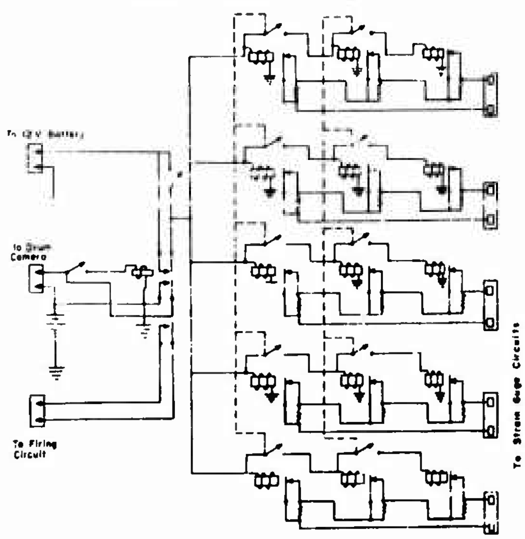
A third calibrator was designed using Western Electric UA-77-47 relays.[8] Three relays with normally closed contacts were used in each pressure-gage circuit. The coils of these relays were connected in parallel and the time of opening of each contact after the application of voltage could be controlled quite accurately by the addition of a small resistance in series with the coils. A calibration sequence was achieved in 15 milliseconds by adjusting each relay to operate with about a five-millisecond delay after operation of the preceding relay. The complete circuit for this calibrator is shown in Figure 9.

2. Measurement of Projectile Velocity

Projectile velocity was obtained by measuring the time interval required for the projectile to travel a given distance. Initially, velocity measurements were made by determining the time interval between the breaking of conducting paths obtained by applying silver paint to two glass microscope slides. The slides were placed in the line of fire and were held two feet apart by supporting stands. Electrically, the slides were part of an RC circuit which produced a sharp voltage pulse when each slide was broken. The pulse circuit is shown in Figure 10. The two pulses from the velocity circuit were displayed on an oscilloscope with time markers applied to the Z-axis. Measurement of the photograph of the oscilloscope trace was used to determine the time between breaking of the slides. The major difficulty[3] with this system was inaccuracy due to lack of precision in measuring the time interval on the photograph.

FIGURE 9

Schematic Drawing of Relay Calibrator



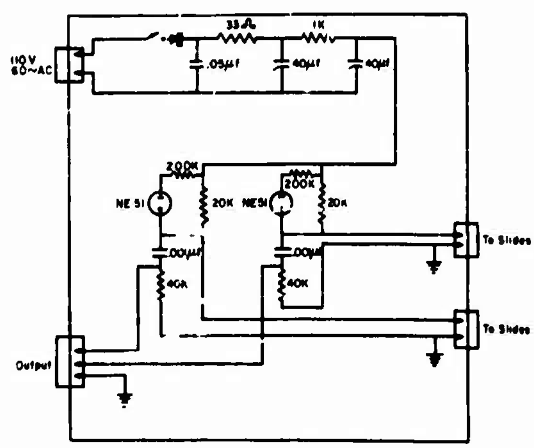
A second method for determining projectile velocity was the use of a 1.6mc counter chronograph in conjunction with either a pair of photoelectric screens, which produced a sharp pulse when the projectile passed through the beam, or with the conducting glass slides. It was found that either the glass slides or the photoelectric screen gave equally good results if time was measured with the counter chronograph.

3. Gun Firing System

Several problems were encountered in the development of a system for firing the gun and triggering the oscilloscopes. The major difficulties were multiple triggering of the oscilloscopes, which obscured the pressure trace and time markers, and erratic time variation between burn-out of the igniter wire and propellant ignition.[4] These problems were eliminated by the development of the firing and triggering circuit shown in Figure 11. The principal innovation was the design of the circuit around three thyratrons (Type 2050), used as relays. The grids are biased negatively and the thyratrons are fired by coupling a positive pulse into the grids. The first of these thyratrons, T1, is used in the circuit to fire the gun. Any external switch* can be used to fire the thyratron. The second thyratron, T2, is used

FIGURE 10

Schematic Drawing of Velocity Circuit Using Glass Slides



*When the drum camera was put into use, a switch on the drum camera which is synchronized with the position of the drum was used to initiate the gage calibration sequence and fire the gun.

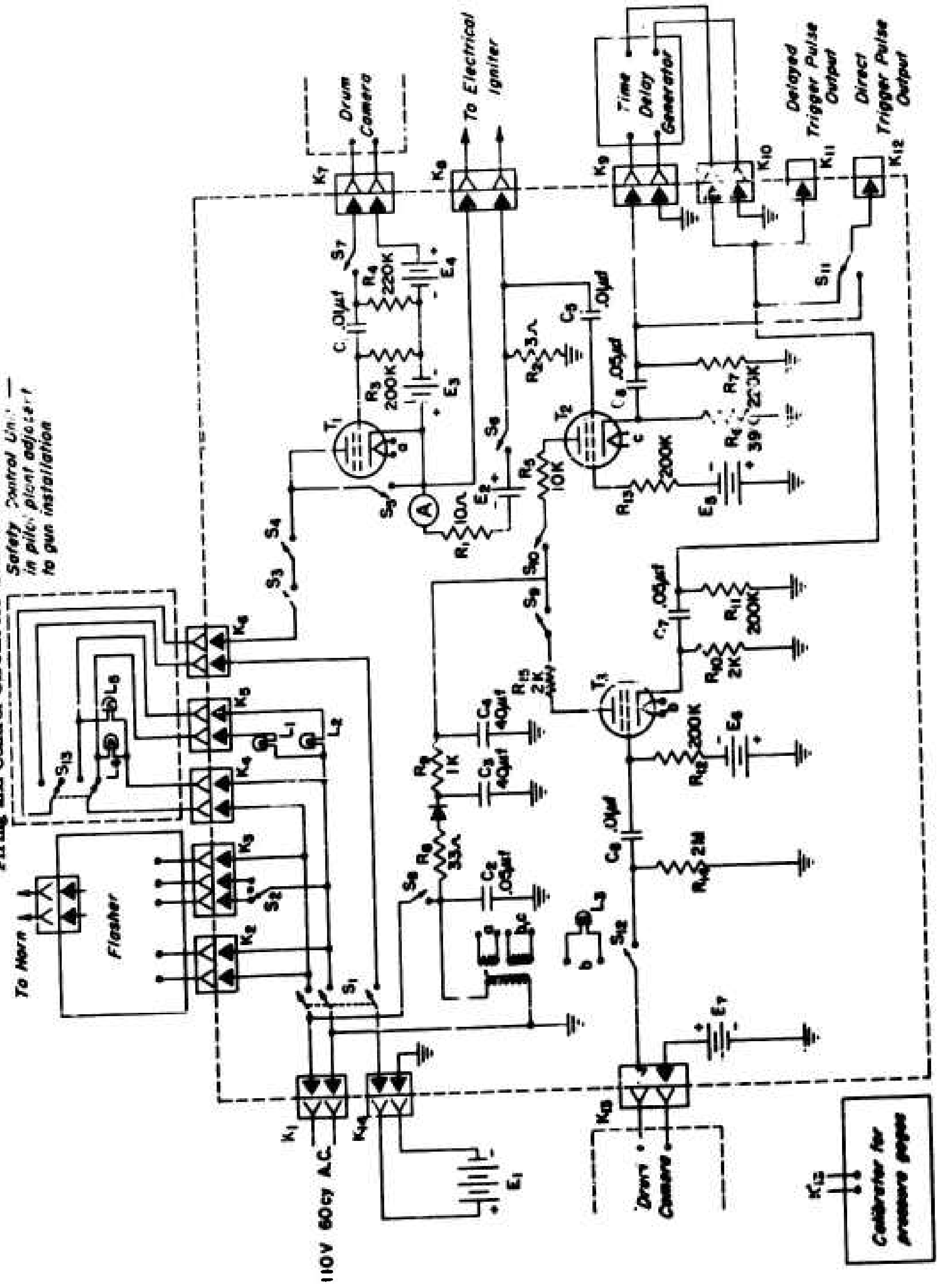


FIGURE 11
Firing and Control Circuit for Gun Installation

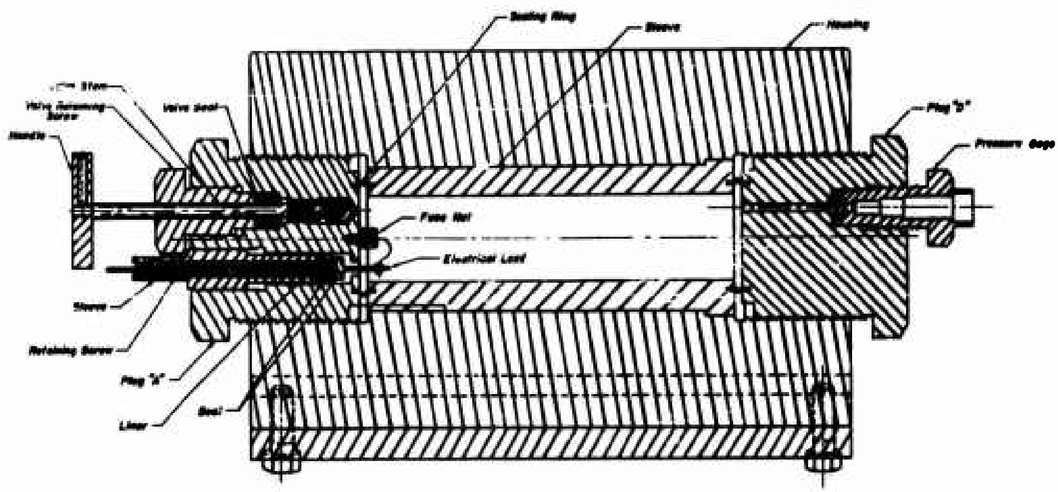
to produce the pulse that triggers the oscilloscopes. The pulse which fires T2 is taken from the high side of a small resistor in the firing line. The output is taken across the cathode resistor and differentiated to produce a short voltage pulse. This arrangement has the advantage that additional triggering pulses cannot be produced until the thyratron has been reset. The triggering pulse can be taken either directly to the oscilloscopes or it can be passed through a preset time-delay generator. The third thyratron, T3, is used to trigger the oscilloscopes for the calibration sequence. Best results were obtained with a time delay between closure of the firing key and triggering of the oscilloscopes of 20 milliseconds and oscilloscope sweep times of 35 to 50 milliseconds.

D. CLOSED BOMB APPARATUS

A closed bomb* was designed and constructed to obtain propellant burning rates. The bomb was tested at pressures up to 40, 000 psi. A complete assembly drawing of the bomb is shown in Figure 12. No instrumentation was developed for use with this equipment.

FIGURE 12

Assembly Drawing of the Closed Bomb



*Nominal chamber volume is 200 cc.

IV. EXPERIMETAL STUDIES IN GUN A

A total of 136 experimental firings were conducted during the period December 1953 to January 1954 in Gun A. Pertinent information for these firings is given in Table I of Appendix A.

A. FIRINGS WITH CONVENTIONALLY LOADED CHARGES OF SPDN 3256

Initial firings in Gun A were made to obtain firing experience and to determine the effect of variation in loading conditions on performance using propellant lot SPDN 3256.* This powder was originally intended for use in the conventional 1.1-inch machine gun. In the original application a 115-gram charge with a 0.917-pound projectile gave a muzzle velocity of 2700 ft/sec with a maximum pressure of about 36,000 psi.

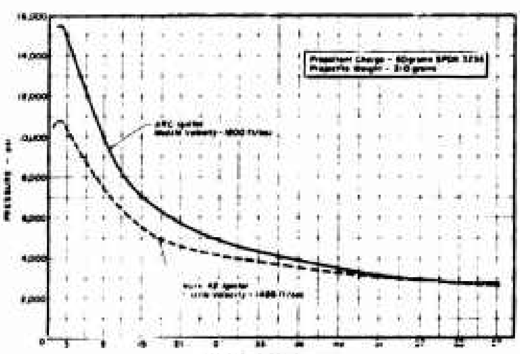
In the experimental firings with SPDN 3256 in Gun A, however, much lower projectile weights and smaller charges were employed. As a result the propellant grains were not completely burned. To obtain acceptable agreement between calculated gun performance and experimental results using propellant burning rates determined from closed-bomb measurements, it was necessary to modify the theoretical form function for these grains. Modification of the form function by assuming different burning rates on the outside of the grain and in the perforation resulted in calculated muzzle velocity in agreement with experimental values;[5] however, the calculated peak pressure was below that obtained experimentally. An empirical form function[6] was derived by calculating a propellant charge design to deliver the observed average pressure-distance curve for specific loading conditions. Good agreement between calculated and observed performance was obtained for other loading conditions with the empirical form function.

The results of firings with SPDN 3256 using both the ARC igniter and the Mark 42 igniter indicated that superior ignition was obtained with the ARC igniter. Experimental pressure-distance curves obtained with the ARC and Mark 42 igniters** for a 60-gram charge of SPDN 3256 with a projectile weight of about 310 grams are shown in Figure 13 as the solid and dashed curves, respectively. The average maximum pressure and muzzle velocity (obtained by measuring time with a counter chronograph) with the ARC igniter were 15,600 psi and 1800 ft/sec while the comparable values with the Mark 42 igniter were 10,700 psi and 1476 ft/sec.

Average muzzle velocity obtained by measuring time between two pips on a photograph of an oscilloscope trace for the same loading conditions and with the ARC igniter was 1933 ft/sec while average muzzle velocity for firings with the Mark 42 igniter under similar conditions was 1752 ft/sec. The difference in muzzle velocity obtained by the

FIGURE 13

Comparison of Average Pressure-Distance Curve Obtained with ARC and Mark 42 Igniters



*Propellant composition and dimensions of the single-perforated grains of SPDN 3256 are as follows:

Composition	Weight Per cent
Nitrocellulose (13.15)	90
Dinitrotoluene	8
Dibutylphthalate	2
Diphenylamine	1

Grain Dimensions

Grain Length	0.271 inch
Grain Outside Diameter	0.080 inch
Perforation Diameter	0.016 inch

**Firings with ARC igniter -- Firings number 26, 27, 28, 29, 35, 39, 53, 54, 55, 65, 94, 95, 108, 109, 110, 111, and 112.
Firings with Mark 42 igniter -- Firings number 30, 34, 37, 38, 40, 50, 51, and 52.

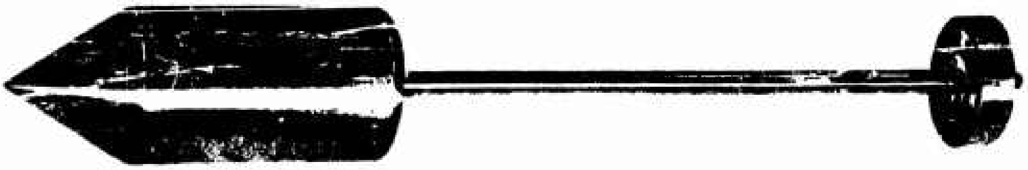
two methods of measurement for these firings is typical of the difference obtained in other firings.

B. FIRINGS WITH JPN OR JPH SHEET PROPELLANT

Several firings were made with conventionally loaded strips of uninhibited JPN sheet propellant both 0.078 and 0.045 inch thick.[3] The strips were approximately 4.5 inches long and 0.125 inch wide. Results were very erratic, but examination of recovered propellant fragments indicated that the propellant distance burned was in good agreement with that theoretically calculated from the observed pressure-time data.

FIGURE 14

Projectile Used for Attached-Charge Firings with JPN Sheet Propellant (Projectile Type D)



In addition to the conventional firings with charges of JPN strip propellant, several firings were made with strip propellant attached to the projectile.[3] The projectile used in this series of firings is shown in Figure 14. Two co-axial cylinders of propellant were supported between the main body of the projectile and the end cap. The outside diameter of the end cap was one-eighth inch less than the inside diameter of the gun bore and openings were machined in the end cap inside the cylinders of propellant to allow propellant gas to flow to the rear. The initial firing made with this system used 0.078-inch-thick JPN sheet inhibited with a 0.003-inch ethyl cellulose film. A progressive charge was obtained by making cuts one-sixteenth inch apart through the inhibitor on both sides of the propellant sheet and parallel to the axis of the projectile. The total propellant weight in this charge arrangement was about 46 grams. Although neither pressure nor muzzle velocity was successfully recorded, they were probably low since recovered portions of the propellant indicated that almost no burning had occurred. To obtain an indication of whether the inhibiting system or the projectile-propellant system caused poor ignition, tests were conducted in which (1) similar inhibited propellant was conventionally loaded along with uninhibited JPN strip propellant, and (2) uninhibited propellant was employed in the attached-charge projectile. Little burning occurred with inhibited sheet when conventionally loaded, although adequate ignition of the attached uninhibited charge was obtained.

A different type of attached charge system was used in a series of firings made with JPH sheet.* Three firings in this series were made with an attached charge fabricated from 0.020-inch-thick disks of propellant the same size as the base of the projectile.[5] Each disk had an eccentric one-fourth-inch diameter hole cut in it. The disks were stacked with the small holes not aligned and cemented together along the edges with a narrow ribbon of cement. The stacks were in turn cemented to the base of the projectile. The attached charges weighed about 15.5 grams and were comprised of 31 disks. In addition to the JPH propellant attached to the projectile, 60 grams of SPDN 3256 was conventionally loaded in each firing. Average pressure versus projectile displacement obtained in these firings is shown by the solid curve in Figure 15. The average muzzle velocity measured in these firings was 2216 ft/sec. The average pressure versus projectile displacement obtained in comparison firings with 60 grams of SPDN and 15.5 grams of

*Firings number 114, 115, 116, 117, 118, and 119.

JPH strip both conventionally loaded is shown by the dashed curve in Figure 15. The average muzzle velocity for these firings was 2302 ft/sec. Both average pressure and muzzle velocity for the conventional rounds were higher than that observed in the firings with the JPH disks attached to the projectile

FIGURE 15

Average Pressure versus Distance for Firings Made with JPH Strip Propellant Conventionally Loaded and Attached to the Projectile

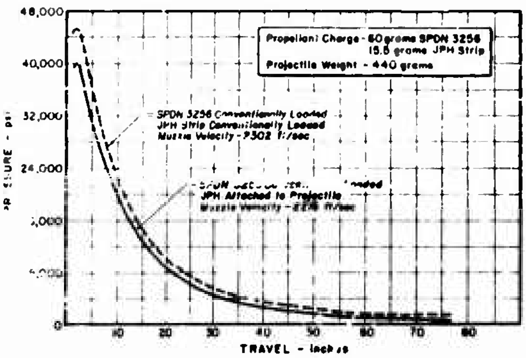
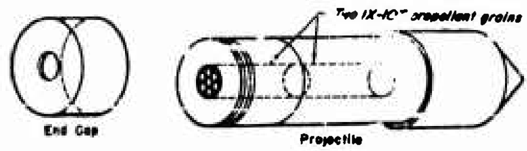


FIGURE 16

Projectile-Propellant System Used in Firings with IX107 Propellant (Projectile Type)

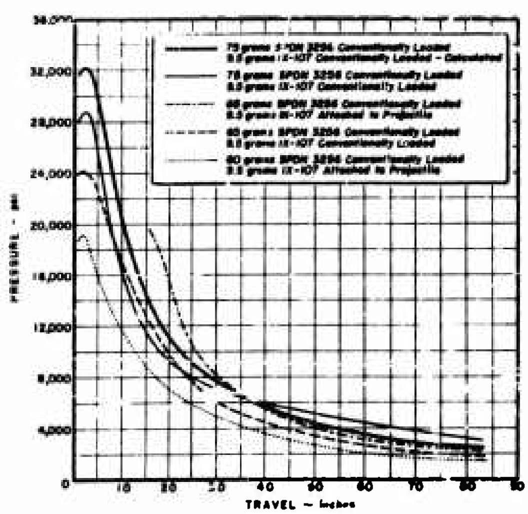


C. FIRINGS WITH IX107 PROPELLANT GRAINS

A small lot of IX107 propellant grains* was obtained from the Naval Powder Factory, Indian Head, Maryland, in order to evaluate this propellant for use in the 1.1-inch gun. These grains were suitable only for preliminary evaluation of the propellant. Following several preparatory rounds using IX107 grains alone, twenty-five rounds were fired using charges composed of combinations of SPDN 3256 and IX107 grains.[2,3] The initial firings using this type charge were made with 60 grams of SPDN 3256 conventionally loaded and two grains of IX107 (9.7 grams) loaded in a cavity in the projectile (425-426 grams),** as shown in Figure 16. The grains were held in place by the end cap, which was screwed over the projectile base. Burned areas were observed at the base of the cavity of the recovered projectiles indicating that ignition of the grains had occurred down the entire length of the perforations. The end cap was deformed during firing, however, enough to allow the propellant to separate from the projectile. Average pressure versus projectile displacement obtained in these firings is shown in Figure 17 as the light dotted curve.

FIGURE 17

Average Pressure versus Projectile Travel for Firings with IX107 Grains in Combination with SPDN 3256



The second series of firings was made using IX107 propellant grains either attached to the projectile or conventionally loaded, in combination

*The composition of IX107 propellant and the dimensions of these grains are as follows:

Composition of IX107 Propellant

	Weight Per cent
Nitrocellulose	30.5
Nitroglycerine	28.9
RDX	39.4
Centralite	1.0
Volatiles	0.2

Dimensions of Seven-Perforated Grain

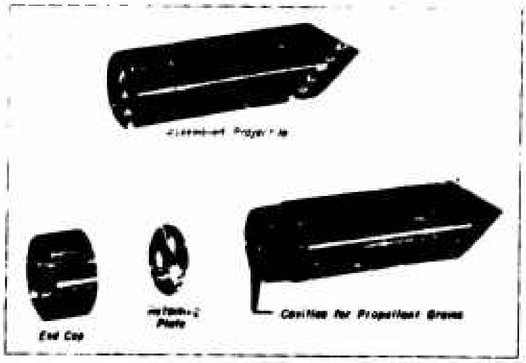
Outside Diameter	0.463 inch
Grain Length	1.117 inches
Perforation Diameter	0.045 inch

**Firings number 48 and 49.

with conventionally loaded SPDN 3256. In this group of firings the thickness of the restraining plate in the end cap was increased to one-eighth inch. Even so, the end cap was deformed enough during firing to permit the propellant grains to escape. All firings in this group were made with 65 grams of SPDN 3256, 3.0 grams of black powder booster, Mark 42 electrical igniters, and two grains of IX107 propellant.* Projectile weights for the two groups were 442 to 446 grams for conventional firings and 436 to 438 grams for the firings using attached IX107 grains. The use of slightly lighter projectiles with the attached charges was based on the assumption that about six grams of unburned propellant would remain in the projectile upon its discharge from the muzzle. In addition to the difference in projectile weights for the two sets of firings, possible differences in the form function of the IX107 grains may have existed. These differences might have resulted from (1) the fact that for conventional firings the grains were uninhibited while in the attached firings the outer grain surface was probably inhibited by a press contact with the wall of the projectile cavity when the propellant was in the cavity and (2) grain breakup of attached IX107 grains associated with deformation of the end cap.[4]

FIGURE 18

Projectile with Cavities for Loading M-7 Propellant Grains (Projectile Type I)



The data do indicate, however, that for the firing conditions employed, somewhat higher average muzzle velocities and quite different average pressures as a function of projectile displacement were obtained with the attached IX107 grains. The average of the muzzle velocities corrected to a temperature of 30°C for conventionally loaded charges was 1897 ft/sec as compared with the average corrected velocity for the attached-charge firings of 1935 ft/sec.[4] Average pressure versus projectile displacement for the attached-charge firings is shown in Figure 17 as the light dot-dashed curve while the light dashed curve was obtained for the comparison rounds fired with the entire charge conventionally loaded.

An additional series of firings was made using 75 grams of SPDN 3256 and two grains of IX107, conventionally loaded with a 433-gram projectile, to obtain data to compare with theoretical calculations.** The average pressure versus projectile displacement obtained in this series is shown in Figure 17 as the light solid curve. Theoretical performance for these loading conditions was calculated using the system of Corner[19] to account for the bi-propellant charge. The results of this calculation are shown in Figure 17 as the heavy solid curve. The theoretical curve is in reasonable agreement with the experimental measurements.

D. FIRINGS WITH M-7 PROPELLANT GRAINS

A series of firings was conducted with a bi-propellant charge composed of 60 grams of SPDN 3256 and approximately 20 grams (three grains) of M-7 propellant.*** These firings were made to compare performance with conventionally loaded M-7 grains to that when these grains are loaded in cavities in the base of the projectile. The projectile used in the attached-charge firings is shown in Figure 18.

Firings were made with SPDN 3256 and M-7 grains both conventionally loaded for three different projectile weights. Average muzzle velocities obtained in these firings were 1925 ft/sec for a 443-gram

*IX107 grains attached to the projectile — Firings number 75, 76, 77, 78, 79, 80, and 81.
IX107 grains conventionally loaded — Firings number 69, 70, 71, 72, 73, and 74.

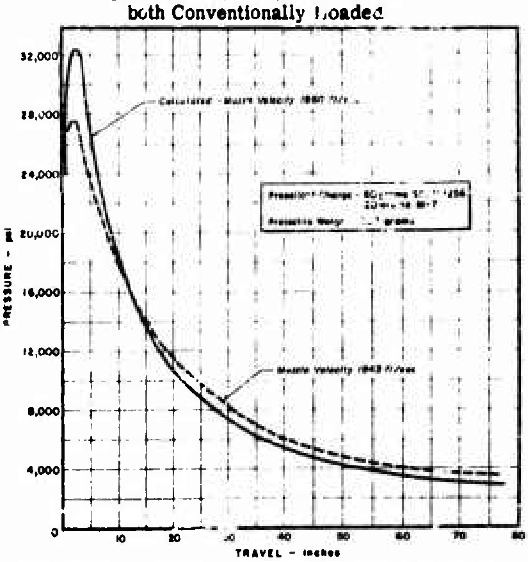
**Firings number 126, 127, 128, 129, 130, 131, 133, and 134.

***The single-perforated M-7 grains used in these firings had an outside diameter of 0.375 inch and an inside diameter of 0.125 inch. For conventional loadings the grains were cut in one-inch lengths. Grains three inches in length were used in attached charges.

projectile,* 1943 ft/sec with a 402-gram projectile,** and 1979 ft/sec with a 385-gram projectile.*** Average pressure as a function of projectile displacement obtained in these firings with a 402-gram projectile is shown in Figure 19 as the dashed curve. Theoretical performance calculated using the empirical form function for SPDN 3256 (see Section A) is also shown in Figure 19 as the solid curve. The calculated muzzle velocity, 1960 ft/sec, is quite close to the average experimental value of 1943 ft/sec. Except that the maximum calculated pressure exceeds the experimental value, the calculated curve is in reasonable agreement with the experimental data.

FIGURE 19

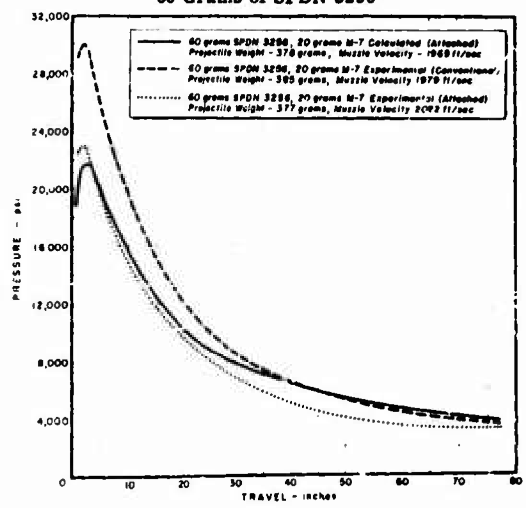
Comparison of Observed Performance with Calculated Performance for a Charge Composed of 60 Grams of SPDN 3256 and 20 Grams of M-7 both Conventionally Loaded



Six rounds were fired with the M-7 propellant grains attached to the projectile. The average maximum pressure measured as a function of projectile travel in these firings is shown as the dotted curve in Figure 20. For comparison the average maximum pressure observed in comparison firings with M-7 grains conventionally loaded is shown in Figure 20 as the dashed curve. These observed pressure curves indicate that the maximum pressure as a function of projectile displacement is reduced when the M-7 grains are attached to the projectile although the average measured muzzle velocity is increased from about 1979 ft/sec to 2022 ft/sec. The calculated performance under the assumption that the M-7 grains are attached to the projectile is shown in Figure 20 as the solid curve. The calculated pressure curve is in good agreement with the observed curve although the calculated muzzle velocity of 1969 ft/sec was low compared to the average value measured under these conditions.

FIGURE 20

Average Pressure versus Projectile Travel for Firings made with 20 Grams of M-7 and 60 Grams of SPDN 3256



E. FIRINGS WITH POROUS GRAINS CAST FROM NITROCELLULOSE BALL POWDER

The linear burning velocity of even the fastest-burning conventional propellants is too low to permit their use as attached, cigarette-burning charges in the 1.1-inch gun. Two possible methods of obtaining a high mass rate of burning are the use of normal propellants with a grain designed to have a large burning surface, and the use of a porous propellant with an extremely high linear burning rate. Porous grains were made by cementing together preplasticized nitrocellulose ball powder.[7] The propel-

*Firings number 83, 84, 85, 86, 87, and 88.

**Firings number 96, 97, 101, 102, 103, 104, 120, 122, 123, 124, and 125.

***Firings number 89, 90, 91, and 92.

lant was cured at 70° F and 1000 psi for 14 hours to form grains of the desired shape.

Grains of this type were cast into an opening three inches deep and one inch in diameter in the base of several projectiles. The charge as cast was approximately 2.5 inches long and weighed approximately 57 grams. The initial firing made with this charge used a standard igniter with five grams of JPN strip around the extension tube to increase the initial pressure. The muzzle velocity recorded was 220 ft/sec and the pressure was too low to measure. The projectile was recovered with most of the propellant intact. There was no visual evidence that burning had occurred. The missing propellant was probably lost when the projectile struck the sand in the gun butt. The length of the propellant grain had been reduced about one-half inch by the setback forces during the firing. A second firing was made with a porous attached charge and 60 grams of SPDN 3256 conventionally loaded. Extremely high pressures in this firing irreparably damaged the barrel and breech of the gun. It is believed that the rapid pressure rise due to the SPDN 3256 broke up the ball powder charge which in turn burned very rapidly to generate the excessive pressure.

V. EXPERIMENTAL STUDIES IN GUN B

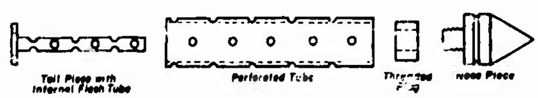
Experimental firings in Gun B were conducted during the period from June 1954 to November 1954. Loading conditions and pertinent measured ballistic data for all firings in Gun B are given in Table II of Appendix A.

A. FIRINGS WITH CONVENTIONALLY LOADED CHARGES OF SPDN 3256

The initial firings in Gun B were designed to test the operation of the gun and instrumentation. These firings were made with a conventionally loaded charge of 90 grams of SPDN 3256. The first 13 firings of this 18-round series were made with projectiles having a phosphor bronze forcing band. Nominal weight of the projectile was 352 grams and weight of the forcing band was about 6 grams. Muzzle velocity of the first seven* of these rounds measured using the photoelectric screens and the counter-chronograph was 2185 ± 78 ft/sec. For the next six firings** the muzzle velocity measured using the conducting glass slides and counter-chronograph was 2185 ± 39 ft/sec.

FIGURE 21

Basket-Type Projectile
(Projectile Type O)



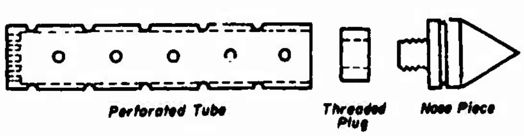
A series of five rounds was fired with no forcing band on the projectiles.*** The average muzzle velocity**** for this series was 1970 ± 60 ft/sec as measured with the photoelectric screens and counter-chronograph. The average value of the peak pressure measured in the firings with the forcing band was 25,900 psi, while the average peak pressure for the firings without the band was 14,800 psi.

B. FIRINGS WITH BASKET-TYPE PROJECTILES

A series of firings was made in which the propellant was loaded in a perforated steel basket attached to the rear of the projectile. Figure 21 is a schematic drawing of one type of basket projectile. This projectile is assembled from four pieces: (1) a nosepiece; (2) a perforated tube with a wall thickness of 0.035 inch; (3) a threaded plug, which is silver soldered in the forward end of the perforated tube and into which the nose is screwed after the propellant is loaded; and (4) a tailpiece and an internal flash tube which is silver soldered into the perforated tube. A flash tube extension from the primer slipped into the permanent flash tube in the basket to ignite the propellant. Four firings were made with projectiles of this type, Firings 163 through 166. In each case, mechanical failure of the projectile basket occurred.[6]

FIGURE 22

Modified Basket-Type Projectile
(Projectile Type O-2)



Six additional firings were made with redesigned basket-type projectiles. The projectiles, shown schematically in Figure 22, were fabricated from heat-treated alloy steel with the tubing and tailpiece an integral part. Fabrication of the nosepiece of the projectile was the same as with the projectile shown in Figure 21. Firings 175 and 176 of this series were made with 50 grams of JPN strip propellant 0.045 inch thick loaded in the basket, while firings 177, 178, 185 and 186 were made with JPH strip propellant fabricated by cementing together two sheets of propellant each 0.0?? inch thick. In each firing structural failure of the basket occurred, usually the tailpiece separating from the body of the basket.[6] No propellant was recovered in any of the projectiles.

*Muzzle velocity measured using photoelectric screens — Firings number 137, 138, 139, 140, 141, 142, and 143.

**Muzzle velocity measured using conducting glass slides — Firings number 144, 145, 146, 147, 148, and 149.

***Firings number 150, 151, 152, 153, and 154.

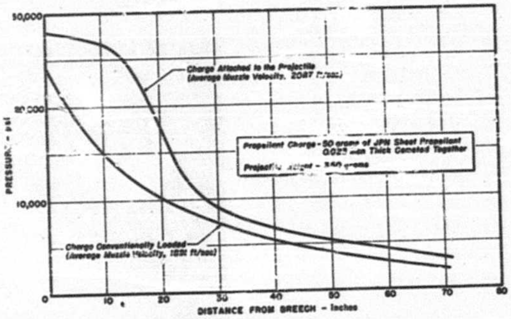
****The velocity recorded for Firing 154 is believed to be incorrect, and is not included.

V. EXPERIMENTAL STUDIES IN GUN B

For comparison, six rounds were fired with cemented JPH strip propellant conventionally loaded. For these firings the projectile was seated in a position such that the effective chamber volume was the same as in the attached firings. A five-inch flash tube was used with the conventional rounds but not with the basket projectiles. Curves of average maximum pressure recorded as a function of distance down the barrel from the breech for the attached-charge firings and for the conventionally loaded comparison rounds are shown in Figure 23. The maximum pressures recorded at the various gage positions are higher with the charge loaded in the basket and a reasonably constant pressure is obtained during the first 15 inches of projectile travel.[9] The average muzzle velocity recorded for the attached-charge firings was 2087 ft/sec as compared with a velocity of 1891 ft/sec with the charge conventionally loaded. Unburned propellant recovered in front of the gun for the conventional firings averaged 0.008 inch thick in good agreement with theoretical predictions.

FIGURE 23

Comparison of Average-Pressure versus Distance from the Breech for Basket-Type Projectile and Conventional Firings



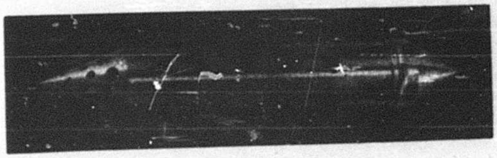
In addition, two firings were made with basket-type projectiles having a conical tail as shown in Figure 24.[9] Theoretically, it is expected that use of such a design would result in the achievement of higher projectile velocities than attained with a square tail because the velocity of the gases away from the projectile would be higher and in turn the impulse effect would be increased. The average muzzle velocity obtained in these firings (Firings 188 and 189) with cemented JPH strip propellant was 2214 ft/sec. In both rounds the tailpiece separated from the body of the basket with no large pieces of the tail being recovered.

C. NINETY-ONE-PERFORATED GRAIN

The optimum propellant grain design for use as an attached charge has a small web and is very progressive. One approach to such a charge is a single ninety-one-perforated grain. A projectile was designed with a cavity in the base into which was cast a ninety-one-perforated double-base grain. These grains were made using plastisol-grade nitrocellulose.[8]

FIGURE 24

Basket-Type Projectile with Conical Tail (Projectile Type Q)



Plastisol-grade nitrocellulose (12.6 per cent N) was made by both the colloid-free and the colloid process to cast these grains. The plastisols had the following composition:

Ingredient	Percentage
Nitrocellulose (12.6 per cent N)	50
Nitroglycerin	45
Diethylphthalate	5

When ninety-one-perforated grains were cast with small-particle nitrocellulose made by the colloid-free process, the mold could not be removed without tearing the grain.* Acceptable grains were cast, however, when the nitrocellulose particles were coated with Kelcoloid LV.

*The propellant adhered to the perforation and was stripped out of the projectile even though the perforation was Teflon coated and the interior of the projectile was threaded for better retention of the propellant grain.

V. EXPERIMENTAL STUDIES IN GUN B

One round, Firing 187, was fired with a ninety-one-perforated grain cast in the base of a projectile as shown in Figure 25.[9] Both muzzle velocity and maximum pressure recorded in the firing were relatively low. The recovered projectile indicated that the end cap had been sheared off during the firing and that no unburned propellant remained in the projectile.

Additional experimental studies with this type projectile were in process when the program was discontinued.

FIGURE 25

Ninety-One-Perforated Grain and Projectile (Projectile Type J-2)

VI. INTERIOR BALLISTIC STUDIES

As a parallel to the experimental gun firings, interior ballistic studies were made to aid in the interpretation of experimental results and in the design of propellant charges.

A. CALCULATED SHOT-START PRESSURE AND RETARDING FORCE ON THE PROJECTILE

A method was developed to calculate, for a given set of loading conditions and with assumed values of maximum pressure and muzzle velocity, explicit values of shot-start pressure and retarding force on the projectile.[8] Using values of average muzzle velocity and maximum pressure recorded in the series of Firings 167-172, shot-start pressure was estimated to be 13,300 psi and the retarding force on the projectile was estimated to be 2850 pounds. These firings were made with conventionally loaded JPN strip propellant 0.045 inch thick. These values of shot-start pressure and retarding force were employed to calculate the performance for firings using a 50-gram charge of JPH strip propellant conventionally loaded. The calculated values of maximum pressure and muzzle velocity were in good agreement with those observed for firings made with this charge.[9]

B. PRESSURE DROP BETWEEN BREECH AND PROJECTILE

Analysis of firing curves in which pressure was measured at various positions down the gun barrel indicated that the pressure drop from the breech to the first gage position just forward of the base of the projectile was greater than predicted by conventional interior ballistic theory.[7] Most interior ballistic systems are of sufficient accuracy to be used for calculating maximum pressure and muzzle velocity for conventional gun systems, but are inadequate for firing conditions in which the propellant burns throughout the time the projectile is in the gun. These systems are also inadequate as a theoretical basis for the comparison of experimental pressures obtained at various bore positions.

Interior ballistic calculations require an accurate relationship for the pressure gradient between the breech and the base of the projectile in order to determine the momentum of the propellant and propellant gases and the acceleration of the projectile. The simplest solutions to the hydrodynamic problems of distribution of pressure, density, and gas velocity between the breech and the base of the projectile are based upon the assumption that the density of the propellant gas is constant down the bore. Based on this assumption the following relationships are obtained:[10]

Velocity Distribution:

$$V = \frac{x}{y}\frac{dy}{dt} \tag{1}$$

Ratio of pressure at breech to pressure on the base of the projectile:

$$\frac{P_b}{P_s} = 1 + \frac{C_1}{2W} \tag{2}$$

where x is the distance from the breech, y the coordinate of the base of the projectile, $\frac{dy}{dt}$ the projectile velocity, P_b the breech pressure, P_s the pressure on the base of the projectile, C_1 the powder mass, and W the projectile mass.

Equation (2) indicates that the relationship between breech and shot pressure is independent of the velocity or displacement of the projectile, in disagreement with the intuitive concept that the pressure gradient should be zero when $y = 0$ and should increase with projectile travel down the bore. Hunt[11] derives Equation (2) and obtains an indirect dependency of the pressure gradient on projectile travel by assuming that the unburned propellant remains at rest in the chamber. Then C_1 in this equation is the weight of the propellant burned, which is indirectly related to the displacement of the projectile.

The more elaborate solution to the hydrodynamic problem given by both Pidduck[12] and Kent[13] for the ratio of pressure at the breech to the pressure on the base of the projectile is:

$$\frac{P_b}{P_s} = 1 + \frac{C_1}{2W} - \frac{1}{24\gamma}\left(\frac{C_1}{W}\right)^2 + \left(\frac{1}{80\gamma} + \frac{1}{360\gamma^2}\right)\left(\frac{C_1}{W}\right)^3 + \cdots \qquad (3)$$

where γ is the ratio of specific heats of the propellant gases. This solution is very close to the conventional approximation given in Equation (2), differing only by terms of higher powers of $\frac{C_1}{W}$, and again does not indicate any dependency of the pressure drop on projectile travel. On the basis of the assumptions made by Pidduck and Kent to describe the hydrodynamic problem, the initial density decreases from breech to projectile in disagreement with the previous assumption of constant density.

The importance of the density gradient on the ratio of breech pressure to pressure on the base of the projectile has been considered[7] making the assumption that the gas density, ρ_ℓ, can be expressed as the polynomial,

$$\rho_\ell = \frac{C_1}{A}\sum_{j=0}^{m}\frac{a_j x^j}{y^{j+1}}$$

where A is the cross section of the base of the projectile, and a_0, a_1 .... a_m are arbitrary constants. Under this assumption, integration of the equation of continuity

$$\frac{d\rho}{dt} + \frac{d}{dx}(\rho v) = 0 \qquad (4)$$

gives the following expression for the velocity of the gases at any position

$$v = \frac{x}{y}\frac{dy}{dt} \qquad (5)$$

which is identical to the expression obtained under the assumption of a constant density.

To determine the ratio of pressure at the breech to pressure at the base of the projectile for the assumed density function, Equation (5) is used together with the equation of motion of the gas

$$\frac{dv}{dt} + v\frac{dv}{dx} = -\frac{1}{\rho}\frac{dP}{dx} \qquad (6)$$

to obtain

$$\frac{P_b}{P_s} = 1 + \frac{C_1}{W}\sum_{j=0}^{m}\frac{a_j}{j+2} \qquad (7)$$

which for a constant density reduces to Equation (2).

If the existence of pressure waves is neglected, the gas density probably decreases monotonically from breech to projectile. For the case in which the density is a quadratic in x

$$\rho = \frac{C_1}{Ay}\left[a_0 + a_1\frac{x}{y} + a_2\left(\frac{x}{y}\right)^2\right]$$

and the density at the breech is 110 per cent of the average density, the constants can be evaluated as follows:

$$a_0 = 1.1$$

$$a_1 = -(0.2 + \frac{2}{3}a_2)$$

$$-0.3 \leq a_2 \geq 0.15$$

The pressure ratio $\frac{P_b}{P_s}$ under these conditions becomes

$$\frac{P_b}{P_s} = 1 + \frac{C_1}{W} \left[\frac{29}{60} + \frac{a_2}{36} \right] \qquad (8)$$

Thus from comparison of Equation (7) with Equation (?) it is concluded that the variation of gas density down the bore has little effect on the magnitude of the ratio of breech to projectile pressure.

C. INTERIOR BALLISTIC SYSTEM FOR ATTACHED CHARGE

An interior ballistic system was developed to calculate the performance for firings in which a conventional propellant charge was attached to the projectile or when part of the propellant was conventionally loaded and part attached to the projectile. In this system the form function of the propellant charge and the propellant burning rate are used to determine an equivalent mass burning rate for an assumed end burning charge attached to the projectile. In general, for conventional propellant charges the system predicts that the gas column to the rear of the projectile flows away from the projectile during the early part of projectile travel and thereafter flows in the same direction as the projectile.

The equations forming the basis of the interior ballistic system are:

Equation of Motion:

$$P_s A - F = M \frac{dV_p}{dt} \qquad (9)$$

Equation of State:

$$P(\upsilon - \eta) = NRT_v \qquad (10)$$

where

$$\upsilon = \frac{V_i + AX}{C_{1j} + C_{2j}} + \frac{1}{\rho} \qquad (10a)$$

and **Equation of State at Rear of Combustion Zone:**

$$P_z = \frac{NRT_p}{\rho_g^{-1} - \eta} \qquad (11)$$

Energy Balance:

$$-\int_{T_v}^{T} C_v (C_{1j} + C_{2j})\, dT = \frac{M' V_p^2}{2} + \int_{-\left(\frac{V_i}{A} + \frac{C_1 + C_2}{\rho A}\right)}^{\left(X - \frac{C_2 - C_{2j}}{\rho A}\right)} \rho_g A V_g^2\, dx + \int_0^X F dx \qquad (12)$$

or assuming a Kent distribution of the propellant and propellant gases to the rear of the combustion zone:

$$C_v (C_{1j} + C_{2j})(T_v - T) = \frac{M' V_p^2}{2} + \frac{C_1 + C_{2j}}{2\delta} (V_p - V_g)^2 + FX \qquad (13)$$

Velocity of Gases Leaving Combustion Zone:

$$V_g = \frac{(\rho - \rho_g)}{\rho_g} r' \qquad (14)$$

Pressure Drop across Combustion Zone:

$$P_s - P_z = \rho r' V_g \qquad (15)$$

Relationship between Space Average Pressure and Pressure at Rear of Combustion Zone:

$$P = P_z + \frac{C_1 + C_{2j}}{8A}\left[\frac{dV_p}{dt} - \frac{dV_g}{dt} - \frac{(V_p - V_g)(V_g + r')}{x + \frac{V_i}{A} + \frac{C_1 + C_{2j}}{\rho A}}\right] \tag{16}$$

Form Functions of Propellant Grains:

$$C_{1j} = \alpha_1 L_1 + \beta_1 L_1^2 + \gamma_1 L_1^3 \tag{17}$$

$$C_{2j} = \alpha_2 L_2 + \beta_2 L_2^2 + \gamma_2 L_2^3 \tag{18}$$

where

$$L_1 = K\int_0^t P^n dt \tag{17a}$$

$$L_2 = K\int_0^t \left(\frac{P_z + P_s}{2}\right)^n dt \tag{18a}$$

Effective Burning Rate of Attached Charge:

$$r' = \frac{1}{\rho A}\frac{dC_{2j}}{dt} = \frac{1}{\rho A}\left(\alpha_2 + 2\beta_2 L_2 + 3\gamma_2 L_2^2\right)\frac{dL_2}{dt} \tag{19}$$

where

- A = cross-sectional area of bore
- C_1 = total unattached charge weight
- C_2 = total attached charge weight
- C_{1j} = weight of C_1 burned at time t
- C_{2j} = weight of C_2 burned at time t
- C_v = specific heat of powder gas at constant volume
- F_R = frictional resistance to projectile motion
- L_1 = distance burned through C_1 grain at time t
- L_2 = distance burned through C_2 grain at time t
- M = total mass being accelerated; M = weight of projectile + C_2 - C_{2j}
- M' = mass accelerated, adjusted for record heat loss, rotation, etc.
- N_R = gas constant
- n = burning rate pressure exponent
- P = space average pressure in tube
- P_z = pressure at flame zone
- P_s = pressure on base of projectile
- P_b = pressure at breech
- r' = effective burning rate of C_2
- T_v = constant volume flame temperature
- T_p = constant pressure flame temperature
- V_p = velocity of projectile with respect to gun
- V_g = velocity of gases leaving flame zone with respect to projectile
- V_1 = velocity with respect to gun of gases at any X-section
- v = specific volume of powder gases
- V_i = initial free volume

W = weight of projectile
X = displacement of projectile from initial pose
x = distance of any X-section from initial position of projectile
γ = ratio of specific heats of propellant gases
a_i, β_i, γ_i = coefficients used in form function
δ = constant used in Kent distribution of gases
η = co-volume of gases
K = burning rate of coefficient
ρ = density of solid propellant
ρ_0 = density of propellant gases leaving flame zone
ρ_x = density of gases at any X-section

These equations are solved using a stepwise, iterative procedure to determine ballistic performance for a given set of loading conditions and propellant parameters.

VII. CONCLUSIONS AND RECOMMENDATIONS

A. GUN RANGE AND INSTRUMENTATION DEVELOPED TO CONDUCT EXPERIMENTAL FIRINGS

A gun range was constructed and an instrumentation system developed to measure ballistic parameters in the experimental firings of modified 1.1-inch guns. The instrumentation system which was evolved during the program was functional and reliable.

The modified 1.1-inch guns were not entirely satisfactory for use in this study. The major difficulty was the extremely small propellant web that could be burned. As a result, the design and fabrication of progressive propellant charges and the procurement of adequate standard test propellant was difficult. If further studies are conducted it is recommended that a 3"/70 caliber gun be employed.

B. PRESSURE AT BREECH MEASURED WITH A PRESSURE GAGE-IGNITER COMBINATION

A pressure gage-igniter combination was developed to measure chamber pressure. With this gage, which fits into the cartridge case, drilling through the receiver into the chamber and aligning this pressure passage with a hole in the cartridge case is eliminated. These gages gave excellent, oscillation-free pressure traces. The major problem with the gage was the effect of the hot gases which surrounded the gage housing on the gage sensitivity.

C. IGNITION OF INHIBITED JPN SHEET PROPELLANT DIFFICULT

A progressive charge was fabricated by inhibiting 0.078 inch thick JPN sheet propellant with a 0.003-inch film of ethyl cellulose and by making cuts one-sixteenth inch apart through the inhibitor on both sides of the sheet. It was found that propellant prepared in this manner was extremely difficult to ignite in gun firings.

D. HIGHER MUZZLE VELOCITIES OBTAINED IN FIRINGS WITH EITHER IX107 OR M-7 GRAINS ATTACHED TO THE PROJECTILE

The average muzzle velocity obtained in firings in which either IX107 or M-7 propellant grains were attached to the projectile in combination with conventionally loaded SPDN 3256 was somewhat higher than the muzzle velocity obtained in comparison firings in which all the propellant charge was conventionally loaded. Comparison of average pressure as a function of projectile travel for the two loading conditions indicated that lower pressures were obtained when the propellant grains were attached.

When either IX107 or M-7 grains were attached to the projectile the end caps which initially restrained the grains in cavities in the projectile base were deformed enough to allow the grains to escape.

E. HIGHER MUZZLE VELOCITIES OBTAINED IN FIRINGS WITH BASKET-TYPE PROJECTILES

The average muzzle velocity recorded for firing in which the propellant was loaded in a steel basket attached to the base of the projectile was about 200 ft/sec higher than the average muzzle velocity recorded in firings with the same charge and projectile weight in which the propellant was conventionally loaded. The maximum pressures recorded at the various gage positions were higher when the charge was loaded in the basket and a reasonably constant pressure was obtained during the first 15 inches of projectile travel.

In each firing with a basket-type projectile structural failure of the basket occurred, usually the tailpiece separating from the body of the basket. No propellant was recovered in any of the projectiles.

F. METHOD DEVELOPED FOR CALCULATION OF THEORETICAL PERFORMANCE OF ATTACHED PROPELLANT CHARGE OR ATTACHED CHARGE IN COMBINATION WITH A CONVENTIONALLY LOADED CHARGE

An interior ballistic system was developed to calculate the theoretical performance for firings in which a conventional charge is attached to the projectile, or when part of the propellant is conventionally loaded and part attached to the projectile. In this system the form function of the propellant charge and the propellant burning rate are employed to determine an equivalent mass burning rate for an assumed end-burning charge attached to the projectile. In general, for conventional propellant charges the calculation predicts that the gases to the rear of the projectile flow away from the projectile during the early part of the projectile travel and thereafter flow in the same direction as the projectile.

A stepwise iterative procedure is employed to solve the equations describing the ballistic system. Calculated performance curves are in reasonable agreement with experiment.

G. DESIGN OF ATTACHED CHARGES USING CONVENTIONAL PROPELLANTS REQUIRES HIGHLY PROGRESSIVE, SMALL-WEB GRAINS

Propellant charges designed with conventional propellants to approach the performance of an impulse gun in the modified 1.1-inch guns require highly progressive grains with small web. The most promising approach was found to be a ninety-one-perforated grain cast in a cavity in the base of a projectile. Successful grains of this type were made with plastisol-grade nitrocellulose. These grains were composed of 50 per cent nitrocellulose (12.6 per cent N), 45 per cent nitroglycerin and 5 per cent diethyl-phthalate. Only one round was fired, however, before the program was terminated. It is suggested that the use of such grains as attached charges be further investigated.

H. MECHANICAL ATTACHMENT OF PROPELLANT CHARGE TO THE PROJECTILE A MAJOR PROBLEM

A major problem in the utilization of conventional propellants in accordance with the attached-charge principal in the modified 1.1-inch gun was mechanical attachment of the propellant to the projectile. The forces involved in accelerating projectiles to high velocities often exceed the strength of both propellant and practical metal parts used to transmit the accelerating force from the projectile to the propellant. In no experimental firing (with a reasonable muzzle velocity) in which part of the attached propellant was not expected to burn did unburned propellant remain in the projectile throughout projectile travel. In addition, even the strongest basket-type projectile employed in this program suffered mechanical failure either during travel in the gun tube or after leaving the bore. It is suggested that further investigation of basket-type projectiles be undertaken to determine the mechanism of structural failure which occurred in experimental firings.

APPENDIX A

Table I

Loading Conditions and Ballistic Parameters for Firings Conducted in Gun A

Firing No.	Propellant	Weight (Gms)	Loading	Projectile Type	Igniter Charge	Booster Charge (Gms)	Projectile Weight (Gms)	Temperature (°F)	Chamber Pressure	Pos. 1 Pressure (psi)	Pos. 2 Pressure (psi)	Pos. 3 Pressure (psi)	Pos. 4 Pressure (psi)	Muzzle Velocity (ft/sec)
1	SPDN 3256	25.0	Conv.	C	–	–	–	–		–	–	–	–	–
2	SPDN 3256	35.0	Conv.	C	9.2 g B.P.	–	–	–		5,000	–	–	–	–
3	SPDN 3256	30.0	Conv.	C	–	–	–	–		–	–	–	–	–
4	SPDN 3256	50.0	Conv.	C	5.0 g B.P.	–	303.1	–		–	–	–	–	–
5	SPDN 3256	50.0	Conv.	C	5.0 g B.P.	–	301.5	–		–	–	–	–	–
6	SPDN 3256	50.0	Conv.	C	5.0 g B.P.	–	–	–		–	–	–	–	1600
7	SPDN 3256	50.0	Conv.	C	5.0 g B.P.	–	301.0	–		–	–	–	–	864
8	SPDN 3256	50.0	Conv.	C	5.0 g B.P.	–	304.0	–		–	–	–	–	–
9	SPDN 3256	60.0	Conv.	C	5.0 g B.P.	–	305.0	–		–	–	–	–	–
10	SPDN 3256	60.0	Conv.	C	5.0 g B.P.	–	304.0	38.0		10,000	4,600	–	–	1363
11	SPDN 3256	47.7	Conv.	C	5.0 g B.P.	8.0	301.5	37.0		–	–	–	–	840
12	SPDN 3256	45.7	Conv.	C	5.0 g B.P.	–	306.5	–		–	–	–	–	939
13	JPN Strip	46.3	Conv.	C	5.0 g B.P.	–	307.0	40.0		–	–	–	–	1077
14	SPDN 3256	43.6	Conv.	C	3.4 g B.P.	14.0	303.0	30.0		–	–	–	–	1064
15	JPN Strip	45.4	Conv.	C	5.4 g B.P.	–	305.0	–		–	–	–	–	1034
16	JPN Strip	45.4	Conv.	C	9.0 g B.P.	–	303.0	42.5		–	–	–	–	1717
17	SPDN 3256	50.0	Conv.	C	7.7 g B.P.	–	305.5	–		15,250	–	–	–	–
18	SPDN 3256	60.0	Conv.	C	5.0 g B.P.	–	305.0	–		–	–	–	–	2044
19	SPDN 3256	46.7	Conv.	C	2.0 g B.P.	5.0	307.0	30.0		–	–	–	–	1075
20	SPDN 3256	45.6	Conv.	C	2.0 g B.P.	5.0	304.0	32.0		–	–	–	–	946
21	SPDN 3256	43.3	Conv.	C	2.0 g B.P.	5.0	304.0	–		9,250	–	–	–	951
22	SPDN 3256	46.0	Conv.	C	2.0 g B.P.	5.0	302.5	–		–	–	21,100	12,500	903
23	SPDN 3256	47.7	Conv.	C	2.0 g B.P.	5.0	303.6	–		–	–	–	–	–
24	SPDN 3256	50.0	Conv.	C	1.3 g B.P.	1.7	307.0	54.0		–	–	–	–	1619
25	SPDN 3256	50.0	Conv.	C	1.2 g B.P.	1.8	300.0	–		–	–	–	–	1290
26	SPDN 3256	60.0	Conv.	C	2.8 g B.P.	2.1	310.0	48.0		–	–	–	–	1618
27	SPDN 3256	60.0	Conv.	C	1.9 g B.P.	2.0	306.0	62.0		–	4,000	–	–	2040
28	SPDN 3256	60.0	Conv.	C	1.9 g B.P.	1.1	306.0	54.5		–	–	–	–	2000
29	SPDN 3256	60.0	Conv.	C	1.7 g B.P.	1.3	308.0	–		–	–	–	–	2000
30	SPDN 3256	60.0	Conv.	C	Mk 42	1.5	309.5	57.0		24,200	–	–	–	1385
31	SPDN 3256	60.0	Conv.	C	Mk 42	2.0	308.0	56.0		–	–	–	–	–
32	SPDN 3256	60.0	Conv.	C	Mk 42	2.0	312.0	52.0		–	–	–	–	–
33	SPDN 3256	60.0	Conv.	C	Mk 42	2.2	306.0	62.5		–	–	–	–	–
34	SPDN 3256	60.0	Conv.	C	Mk 42	2.5	300.0	62.0		–	–	–	–	1867
35	SPDN 3256	60.0	Conv.	C	2.5 g B.P.	0.7	312.5	52.0		–	28,480	–	–	1867
36	JPN Strip	45.0	Att.	D	3.0 g B.P.	–	–	–		–	7,500	–	–	–
37	SPDN 3256	60.0	Conv.	C	Mk 42	2.0	310.0	75.0		–	–	–	–	1735
38	SPDN 3256	60.0	Conv.	C	Mk 42	2.0	318.0	76.0		–	–	–	–	1836
39	SPDN 3256	60.0	Conv.	C	1.0 g B.P.	2.0	311.0	66.5		12,700	–	–	–	1804
40	SPDN 3256	60.0	Conv.	C	Mk 42	2.4	311.0	70.0		–	4,500	3,800	–	1746
41	JPN Strip	50.5	Conv.	C	1.0 g B.P.	2.0	310.0	81.0		10,800	–	–	–	1748
42	JPN Strip	44.0	Att.	D	1.0 g B.P.	1.0	336.4	72.0		–	–	–	–	–
43	JPN Strip	50.2	Conv.	C	1.0 g B.P.	2.0	313.0	71.0		–	–	–	–	493
44	IX 107	23.6	Conv.	C	1.0 g B.P.	2.0	306.0	76.0		–	–	–	–	–
45	IX 107	28.2	Conv.	C	3.5 g B.P.	1.0	309.0	–		–	–	–	–	493
46	IX 107	9.3	Conv.	C	1.0 g B.P.	2.0	310.0	–		6,800	–	–	–	472
47	JPN Strip SPDN 3256 IX 107	40.6 60.0 9.6	Conv. Conv. Conv.	C	1.0 g B.P.	2.0	310.0	66.0		–	–	–	–	2000
48	SPDN 3256 IX 107	60.0 9.4	Conv. Att.	F	Mk 42	3.5	425.4	–		6,[illegible]00	6,800	–	–	1383
49	SPDN 3256 IX 107	60.0 8.9	Conv. Att.	F	Mk 42	2.5	426.5	–		10,200	8,100	4,800	2,800	1946
50	SPDN 3256	60.0	Conv.	C	Mk 42	2.5	310.0	–		–	–	–	–	1417
51	SPDN 3256	60.0	Conv.	C	Mk 42	4.5	310.0	–		9,000	5,100	–	–	1804
52	SPDN 3256	60.0	Conv.	C	Mk 42	2.5	306.[illegible]	60.0		12,500	4,700	–	900	1647
53	SPDN 3256	60.0	Conv.	C	1.0 g B.P.	2.5	311.6	–		15,000	6,200	–	–	1751
54	SPDN 3256	60.0	Conv.	C	1.0 g B.P.	2.5	311.0	70.0		–	5,750	–	–	1608
55	SPDN 3256	60.0	Conv.	C	1.0 g B.P.	2.5	311.0	70.0		16,500	16,500	3,800	2,800	1765
56	JPN Strip	33.0	Att.	D	3.1 g B.P.	–	334.4	–		6,000	5,000	–	–	882
57	JPN Strip	33.0	Conv.	C	1.6 g B.P.	1.5	321.0	–		6,000	4,800	–	1,800	942
58	JPN Strip	33.0	Conv.	C	1.5 g B.P.	1.5	322.0	–		–	–	–	–	836
59	SPDN 3256	90.0	Conv.	C	Mk 42	2.5	311.0	–		–	19,250	16,780	3,200	2360
60	SPDN 3256	90.0	Conv.	C	1.0 g B.P.	2.5	311.0	95.0		–	–	–	–	2331
61	SPDN 3256	90.0	Conv.	C	1.0 g B.P.	2.5	311.0	100.0		–	–	–	–	2419
62	SPDN 3256 IX 107	60.0 9.6	Conv. Conv.	C	1.0 g B.P.	2.0	311.0	100.0		10,200	4,000	–	3,175	1770
63	SPDN 3256 IX 107	60.0 7.8	Conv. Att.	F	Mk 42	2.5	434.2	100.0		–	–	–	–	1753
64	SPDN 3256	60.0	Conv.	C	1.0 g B.P.	2.5	323.0	84.0		13,700	4,000	3,280	–	1708
65	SPDN 3256	60.0	Conv.	C	1.0 g B.P.	2.0	300.0	93.0		–	–	–	–	1796
66	JPN Strip	50.0	Conv.	C	1.0 g B.P.	2.0	[illegible]	107.0		11,000	5,000	–	3,900	1731
67	IX 107	60.0	Conv.	G	Mk 42	1.4	443.0	88.0		–	–	–	–	606
68	IX 107	60.0	Conv.	G	Mk 42	2.1	446.0	90.0		–	–	–	–	420
69	SPDN 3256 IX 107	65.0 9.7	Conv. Conv.	G	Mk 42	3.0	444.0	99.0		–	–	–	3,200	1860
70	SPDN 3256 IX 107	65.0 9.7	Conv. Conv.	G	Mk 42	3.0	446.0	75.0		24,200	–	–	3,800	1867
71	SPDN 3256 IX 107	65.0 9.7	Conv. Conv.	G	Mk 42	3.0	445.0	76.0		–	–	–	3,600	1867
72	SPDN 3256 IX 107	65.0 9.7	Conv. Conv.	G	Mk 42	3.0	444.0	83.0		–	–	–	–	1860
73	SPDN 3256 IX 107	65.0 9.7	Conv. Conv.	G	Mk 42	3.0	442.0	78.0		–	–	–	–	1906
74	SPDN 3256 IX 107	65.0 9.7	Conv. Conv.	G	Mk 42	3.0	445.0	82.0		–	10,800	4,800	2,080	1860
75	SPDN 3256 IX 107	65.0 9.2	Conv. Att.	F	Mk 42	3.0	436.1	87.0		–	–	–	–	1956
76	SPDN 3256 IX 107	65.0 3.2	Conv. Att.	F	Mk 42	3.0	437.0	91.0		–	–	–	3,700	1800
77	SPDN 3256 IX 107	65.0 8.7	Conv. Att.	F	Mk 42	3.0	437.0	85.0		–	18,800	–	–	–
78	SPDN 3256 IX 107	65.0 8.9	Conv. Att.	F	Mk 42	3.0	436.0	92.0			–	6,200	–	1838
79	SPDN 3256 IX 107	65.0 9.2	Conv. Att.	F	Mk 42	3.0	437.5	98.0		–	–	–	–	1934
80	SPDN 3256 IX 107	65.0 8.7	Conv. Att.	F	Mk 42	3.0	438.0	97.5		–	–	–	3,750	1861

APPENDIX A

Table I (Cont'd)

Loading Conditions and Ballistic Parameters for Firings Conducted in Gun A

Firing No	Propellant	Weight (Gms)	Loading	Projectile Type	Igniter Charge	Booster Charge (Gms)	Projectile Weight (Gms)	Temperature (°F)	Chamber Pressure	Pos. 1 Pressure (psi)	Pos. 2 Pressure (psi)	Pos. 3 Pressure (psi)	Pos. 4 Pressure (psi)	Muzzle Velocity (ft/sec)
81	SPDN 3256 IX 107	65.0 9.4	Conv. Att.	F	Mk 42	3.0	433.0	77.0	—	—	12,750	5,750	3,750	1803
82	M-7	58.0	Conv.	G	1.0 g B.P.	2.0	444.0	87.0	—	—	—	—	—	704
83	SPDN 3256 M-7	60.0 20.0	Conv. Conv.	G	1.5 g B.P.	3.0	442.0	94.0	—	—	—	—	—	—
84	SPDN 3256 M-7	60.0 20.0	Conv. Conv.	G	1.5 g B.P.	3.0	442.0	94.0	—	—	—	—	—	—
85	SPDN 3256 M-7	60.0 20.5	Conv. Conv.	G	1.0 g B.P.	2.0	443.5	90.0	—	—	4,000	—	—	1893
86	SPDN 3256 M-7	60.0 20.7	Conv. Conv.	G	1.0 g B.P.	2.0	443.2	96.0		—	11,100	11,400	—	1951
87	SPDN 3256 M-7	60.0 20.0	Conv. Conv.	G	1.0 g B.P.	2.0	443.0	97.0	—	—	16,750	10,[illegible]	4,100	1632
88	SPDN 3256 M-7	60.0 21.0	Conv. Conv.	G	1.0 g B.P.	2.0	442.3	85.0	—	—	—	—	6,800	1385
89	SPDN 3256 M-7	60.0 20.4	Conv. Conv.	G	1.0 g B.P.	2.0	383.8	101.0	—	31,850	12,300		—	2002
90	SPDN 3256 M-7	60.0 20.6	Conv. Conv.	G	1.0 g B.P.	2.0	391.7	100.0	—	28,500	12,750	11,800	8,000	1984
91	SPDN 3256 M-7	60.0 20.4	Conv. Conv.	G	1.0 g B.P.	2.0	384.0	94.0	—	—	—		4,800	1984
92	SPDN 3256 M-7	60.0 20.0	Conv. Conv.	G	1.0 g B.P.	2.0	382.0	100.0	—	—	—	—	—	1943
93	SPDN 3256	65.0	Conv.	C	1.0 g B.P.	2.0	308.0	88.0	—	13,800	6,000			1912
94	SPDN 3256	60.0	Conv.	C	1.0 g B.P.	2.0	323.0	83.0	—	—	—	—		1742
95	SPDN 3256	60.0	Conv.	C	1.0 g B.P.	2.0	324.0	83.0	—	—	—	—	—	1735
96	SPDN 3256 M-7	60.0 20.0	Conv. Conv.	G	1.0 g B.P.	2.0	402.0	92.0	—	—	—	—	—	1933
97	SPDN 3256 M-7	60.0 20.0	Conv. Conv.	G	1.0 g B.P.	2.0	401.0	85.0	—	28,400	11,300	900	3,000	2016
98	SPDN 3256 M-7	60.0 20.0	Conv. Att.	I	1.0 g B.P.	2.0	377.4	85.0	—	—	—	—	—	2034
99	SPDN 3256 M-7	60.0 20.0	Conv. Att.	I	1.0 g B.P.	2.0	378.0	84.0	—	63,500	10,800	5,400	4,000	2015
100	SPDN 3256 M-7	60.0 20.0	Conv. Att.	I	1.0 g B.P.	2.0	377.0	82.5	—	13,000	10,000	6,800	2,800	2004
101	SPDN 3256 M-7	60.0 20.0	Conv. Conv.	G	1.0 g B.P.	2.0	401.0	82.0	—	—	—	3,500	5,300	1960
102	SPDN 3256 M-7	60.0 20.0	Conv. Conv.	G	1.0 g B.P.	2.0	400.0	83.0	—	—	—	—	—	1918
103	SPDN 3256 M-7	60.0 20.0	Conv. Conv.	G	1.0 g B.P.	2.0	402.0	84.0	—	—	—	—		—
104	SPDN 3256 M-7	60.0 20.0	Conv. Conv.	G	1.0 g B.P.	2.0	401.0	84.0	—	—	10,800	—	6,250	1875
105	SPDN 3256 M-7	60.0 20.0	Conv. Att.	I	1.0 g B.P.	2.0	375.0	83.5	—	23,300	—	4,000	3,600	2030
106	SPDN 3256 M-7	60.0 20.0	Conv. Att.	I	1.0 g B.P.	2.0	378.0	80.0	—	23,800	—	3,800	3,600	2006
107	SPDN 3256 M-7	60.0 20.0	Conv. Att.	I	1.0 g B.P.	2.0	376.0	88.0	—	23,300	9,800	6,800	4,300	—
108	SPDN 3256	60.0	Conv.	C	1.5 g B.P.	2.0	307.0	74.5	—	15,500	7,800	—	—	1840
109	SPDN 3256	60.0	Conv.	C	1.5 g B.P.	2.0	312.0	67.0	—	16,000	6,000	—	2,000	1827
110	SPDN 3256	60.0	Conv.	C	1.5 g B.P.	2.0	310.5	67.0	—	16,300	6,000	6,000	4,000	1888
111	SPDN 3256	60.0	Conv.	C	1.5 g B.P.	2.0	308.5	82.5	—	—	—	—	—	1904
112	SPDN 3256	60.0	Conv.	C	1.5 g B.P.	2.0	311.0	73.0	—	—	—	—	—	1884
113	SPDN 3256	60.0	Conv.	C	1.5 g B.P.	2.0	310.0	78.5	—	18,600	6,400		1,400	1833
114	SPDN 3256 JPH Strip	60.0 15.5	Conv. Att.	G	Mk 42	3.0	443.0	77.0	—	45,000	10,000	7,800	3,000	2176
115	SPDN 3256 JPH Strip	60.0 15.5	Conv. Att.	G	Mk 42	3.0	442.0	52.0	—	—	—	5,400	3,800	2337
116	SPDN 3256 JPH Strip	60.0 15.5	Conv. Att.	G	Mk 42	3.0	442.0	41.0	—	46,300	9,800	4,000	1,800	2142
117	SPDN 3256 JPH Strip	60.0 15.4	Conv. Conv.	G	Mk 42	3.0	440.0	44.0	—	43,000	10,000	5,250	—	2313
118	SPDN 3256 JPH Strip	60.0 15.4	Conv. Conv.	G	Mk 42	3.0	441.5	51.0	—	38,300	9,800	2,000	1,500	2383
119	SPDN 3256 JPH Strip	60.0 15.4	Conv. Conv.	G	Mk 42	3.0	441.0	51.0	—	38,800	9,300	2,800	—	2310
120	SPDN 3256 M-7	60.0 20.0	Conv. Conv.	G	1.0 g B.P.	2.0	402.0	88.0	—	—	—	—	—	1990
121	SPDN 3256	60.0	Conv.	C	1.0 g B.P.	2.0	306.5	87.0	—	—	—	—	—	1800
122	SPDN 3256 M-7	60.0 20.0	Conv. Conv.	G	1.0 g B.P.	2.0	[illegible]	87.0	—	28,500	12,750	6,800	5,250	2076
123	SPDN 3256 M-7	60.0 20.0	Conv. Conv.	G	1.0 g B.P.	2.0	404.0	85.5	—	28,250	12,500	6,300	2,500	1898
124	SPDN 3256 M-7	60.0 20.4	Conv. Conv.	G	0.15 g B.P.	2.5	404.0	34.0	—	—	13,000	5,800	—	1886
125	SPDN 3256 M-7	60.0 20.2	Conv. Conv.	G	0.1 g B.P.	2.5	402.0	34.0	—	27,750	12,750	5,900	4,800	1906
126	SPDN 3256 IX 107	70.0 9.9	Conv. Conv.	G	0.1 g B.P.	2.4	433.0	31.0	—	—	8,800	5,900	5,800	1771
127	SPDN 3256 IX 107	70.0 9.9	Conv. Conv.	G	—	2.5	433.0	32.0	—	36,800	8,800	6,000	—	1872
128	SPDN 3256 IX 107	70.0 10.3	Conv. Conv.	G	—	2.5	432.0	33.0	40,000	39,600	10,800	7,300	4,600	1861
129	SPDN 3256 IX 107	70.0 10.1	Conv. Conv.	G	—	2.5	436.0	32.0	—	—	—	—	—	1827
130	SPDN 3256 IX 107	70.0 9.6	Conv. Conv.	G	—	2.5	432.5	40.0	—	30,800	10,300	6,700	5,300	—
131	SPDN 3256 IX 107	70.0 9.6	Conv. Conv.	G	—	2.5	435.0	38.0	38,400	38,400	9,000	6,800	4,400	—
132	JPN Strip D.B.	5.0	Conv. Att.	M	—	2.5	—	36.0	—	—	—	—	—	230
133	SPDN 3256 IX 107	70.0 9.5	Conv. Conv.	G	—	2.5	434.0	41.0	32,000	29,250	—	6,000		1807
134	SPDN 3256 IX 107	70.0 9.5	Conv. Conv.	G	—	2.5	434.0	30.0	—	—	—	—	—	1926
135	SPDN 3256 IX 107	70.0 9.5	Conv. Att.	F	0.5 g B.P.	2.0	433.0	32.0	—	30,400	13,800	—	—	1874
136	SPDN 3256 D.B.	60.0 56.6	Conv. Att.	M	0.5 g B.P.	2.0	370.0	41.0	—	—	—	—	—	1880

APPENDIX A

Table II

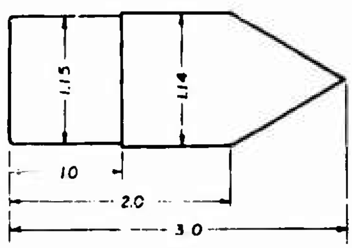
Loading Conditions and Ballistic Parameters for Firings Conducted in Gun B

Firing No.	Propellant	Weight (Gms)	Loading	Projectile Type	Igniter Charge	Booster Charge (Gms)	Projectile Weight (Gms)	Temperature (°F)	Chamber Pressure	Pos. 1 Pressure (psi)	Pos. 2 Pressure (psi)	Pos. 3 Pressure (psi)	Pos. 4 Pressure (psi)	Muzzle Velocity (ft/sec)
137	SPDN 3256	90.0	Conv	P	Charge in Primer Small Fraction of Total Igniter Charge	2.5	[illegible]	82.0	No Chamber Pressure Recorded	24,000	18,000	–	7,200	2200
138	SPDN 3256	90.0	Conv.	P		2.5	357.0	Temperature of all Rounds 80°F ± 5°F		19,000	14,500	–	–	2000
139	SPDN 3256	90.0	Conv.	P		2.5	357.0				–	–	–	2100
140	SPDN 3256	90.0	Conv.	P		[illegible]	350.0			27,500	23,[illegible]00	–	4,700	2203
141	SPDN 3256	90.0	Conv.	P		2.5	354.0			–	–	–	–	2119
142	SPDN 3256	90.0	Conv.	P		2.5	354.0			30,500	23,000	–	12,000	2066
143	SPDN 3256	90.0	Conv.	P		2.5	360.0			–	–	–	–	2004
144	SPDN 3256	90.0	Conv.	P		2.5	357.0			27,000	16,000	5,000	–	2110
145	SPDN 3256	90.0	Conv.	P		2.5	355.0			30,[illegible]	14,000	6,000	–	2100
146	SPDN 3256	90.0	Conv.	P		2.5	356.0			–	18,500	5,700	7,000	2266
147	SPDN 3256	90.0	Conv.	P		2.5	356.0			26,000	18,000	–	6,000	2104
148	SPDN 3256	90.0	Conv.	P		2.5	357.0			37,000	20,000	–	6,500	2250
149	SPDN 3256	90.0	Conv.	P		2.5	357.0			24,500	18,200	–	5,000	2136
150	SPDN 3256	90.0	Conv.	P		2.5	352.5			18,000	12,000	–	4,000	1800
151	SPDN 3256	90.0	Conv.	P		2.5	356.0			13,000	13,000	–	4,000	2013
152	SPDN 3256	90.0	Conv.	P		2.5	352.0			14,500	12,000	–	6,000	2010
153	SPDN 3256	90.0	Conv.	P		2.5	350.0			16,000	8,900	–	–	2007
154	SPDN 3256	90.0	Conv.	P		2.5	354.0			14,500	9,750		–	2716
155	JPN Strip	90.0	Conv.	P		2.5	354.0			50,000	16,200	–	6,[illegible]00	2002
156	JPN Strip	80.0	Conv.	P		2.5	356.0			46,000	9,800	7,200	–	830
157	JPN Strip	80.0	Conv.	P	Black Powder	2.5	357.0			–	–	–	–	2427
158	JPN Strip	80.0	Conv.	P		2.5	356.0			50,500	–	–	–	2600
159	JPN Strip	90.0	Conv.	P		2.5	357.0			47,000	17,500	–	–	2470
160	JPN Strip	80.0	Conv.	P		2.5	[illegible]			53,000	–	–	–	2400
161	JPN Strip	80.0	Conv.	P		2.5	357.0			62,500	11,000		6,000	2481
162	JPN Strip	80.0	Conv.	P		2.5	357.0			58,700	12,000	–	6,0[illegible]	2553
163	JPN Strip	80.0	Att.	O	2.5 g B.P.	No flash tube	355.0			46,000	11,500	10,000	4,300	2404
164	JPN Strip	80.0	Att.	O	2.0 g B.P.		348.7			15,000	7,500	4,000	2,500	1266
165	JPN Strip	80.1	Att.	O	1.5 g B.P.		340.1			–	–	–	–	1406
166	JPN Strip	80.0	Att.	O	1.5 g B.P.		351.0			12,000	7,000	4,200	2,000	1906
167	JPN Strip	80.0	Conv.	P	–	1.5	358.6			–	–	–	–	1817
168	JPN Strip	80.0	Conv.	P	–	1.5	350.7			–	–	–	–	1871
169	JPN Strip	80.0	Conv.	P	–	1.5	354.5		13,500	–	–	–	–	1707
170	JPN Strip	80.0	Conv.	P	–	1.5	355.7		11,000	14,700	–	4,000	2,700	1774
171	JPN Strip	80.0	Conv.	P	–	1.5	358.9		26,000	16,000	8,000	–	4,200	1870
172	JPN Strip	80.0	Conv.	P	–	1.5	360.2		26,000	14,500	3,500	–	3,000	1851
173	JPN Strip	80.0	Att.	O	1.5 g B.P.	No flash tube	355.5		22,000	12,700	7,000	–	2,500	1922
174	JPN Strip	80.0	Att.	O	1.5 g B.P.		352.2		22,000	15,000	6,750	–	–	1666
175	JPN Strip	80.0	Att.	O-2	1.5 g B.P.		340.4		24,000	–	6,000	–	–	1640
176	JPN Strip	80.0	Att.	O-2	1.5 g B.P.		340.2		26,000	26,500	–	–	–	–
177	JPN Strip	80.0	Att.	O-2	1.5 g B.P.		342.0		23,000	22,000	10,000	6,000	–	2006
178	JPN Strip	80.0	Att.	O-2	1.5 g B.P.		345.0		23,000	25,000	9,000	–	5,000	2023
179	JPN Strip	80.0	Conv.	P Mod 1		1.5	343.4		–	–	–	–	–	1872
180	JPN Strip	80.0	Conv.	P Mod 1	–	1.5	348.7		26,000	13,000	–	11,000	1,000	1238
181	JPN Strip	80.0	Conv.	P Mod 1	–	1.5	344.6		13,[illegible]00	13,000	–	–	–	1800
182	JPN Strip	80.0	Conv.	P Mod 1	–	1.5	[illegible]		20,240	19,0[illegible]0	–	–	–	1627
183	JPN Strip	80.0	Conv.	P Mod 1	–	1.5	345.6		22,[illegible]00	–	–	–	1,000	2000
184	JPN Strip	80.0	Conv.	P Mod 1	–	1.5	344.[illegible]		–	13,[illegible]00	–	2,000	1,000	1762
185	JPN Strip	80.0	Att.	O-2	1.5 g B.P.	No flash tube	344.9		26,000	20,500	10,000	–	4,000	2047
186	JPN Strip	80.0	Att.	O-2	1.5 g B.P.		344.6		30,000	23,500	9,000	–	4,200	2188
187	D.B.	48.2	Att.	J-2	1.5 g B.P.		352.5		19,000	15,000	3,000	–	–	1970
188	JPN Strip	80.1	Att.	Q	1.5 g B.P.		332.2		–	25,000	7,000	–	3,000	2226
189	JPN Strip	80.0	Att.	Q	1.5 g B.P.		310.1		34,200	31,000	9,300	3,000	4,000	2272
190	JPN Strip	80.0	Conv.	P Mod 1	Pb Styph.	1.5	343.0		–	–	–	–	–	2307
191	JPN Strip	80.0	Conv.	P Mod 1	Pb Styph.	1.5	345.5		–	–	–	–	–	2300

APPENDIX B

Additional Projectile Types

Projectile Type C



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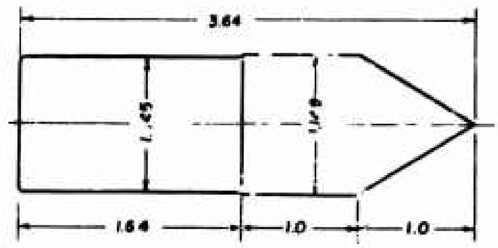

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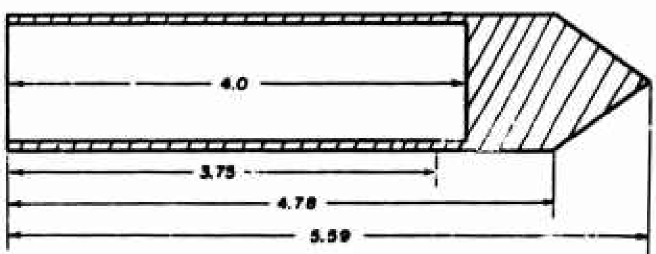
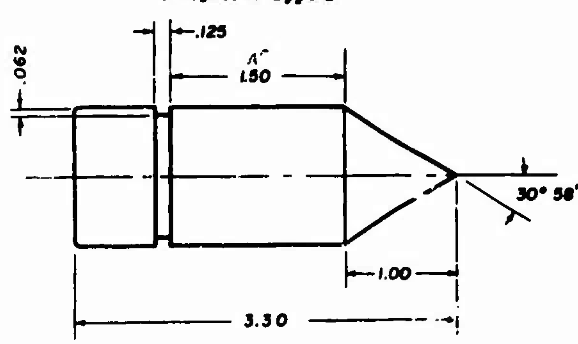


Projectile Type P



*Projectile Type P Mod I, Dimension A is 0.25

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